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LUNAR SURFACE ROVING VEHICLE. VOLUME 2:  
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**GENERAL MOTORS CORPORATION**

# DESIGN AND MANUFACTURE OF WHEELS FOR A DUAL-MODE (MANNED - AUTOMATIC) LUNAR SURFACE ROVING VEHICLE

Prepared for

GEORGE C. MARSHALL SPACEFLIGHT CENTER  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
Marshall Spaceflight Center, Alabama 35812  
Under Contract NAS 8-25194

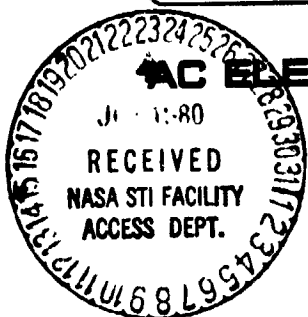


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## LUNAR SYSTEMS

AC ELECTRONICS • DEFENSE RESEARCH LABORATORIES

**SANTA BARBARA, CALIFORNIA**



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MAY 1970

GENERAL MOTORS CORPORATION

FINAL REPORT ON  
**DESIGN AND MANUFACTURE OF  
WHEELS FOR A DUAL-MODE  
(MANNED - AUTOMATIC)  
LUNAR SURFACE ROVING VEHICLE**

VOLUME I DETAILED TECHNICAL REPORT

Prepared for

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## FOREWORD

This final report has been prepared to present the results of testing and evaluation of wheel design concepts developed for a dual-mode (manned/automated) Lunar Surface Roving Vehicle. The work was accomplished by AC Electronics - Defense Research Laboratories at Goleta, California.

This report, Volume I, a detailed technical report along with Volume II, a Development Test Plan for Wheel and Wheel Drive Assembly of a Dual-Mode (manned/automated) Lunar Surface Roving Vehicle have been prepared to fulfill the final report requirements on Contract NAS8-25194.

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## SUMMARY

This volume of the final report presents a detailed technical report of the concept development, testing, evaluation and the selection of a final wheel design concept for a Dual-Mode Lunar Surface Roving Vehicle (DLRV).

Initially two wheel design concepts were selected. This selection was based on the review of related programs and applicable technology. Three wheel configurations were chosen, one open wheel and two closed wheel. Wheels of these configurations were fabricated for testing. As a result of initial testing a closed wheel of a fourth configuration was fabricated of parts of one of the earlier closed wheels.

At the conclusion of a series of soft soil, mechanical, and endurance tests a final wheel design concept was developed and presented to the National Aeronautics and Space Administration for approval. Upon approval, three wheels of this final configuration were fabricated and assembled for delivery to and evaluation by the National Aeronautics and Space Administration.

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## SECTION I INTRODUCTION

AC Electronics - Defense Research Laboratories (AC-DRL) for several years has had under development various lunar wheel as well as total vehicle concepts. A thorough review and analysis of past works at AC-DRL was undertaken. In addition, published reports and data from the work of others in the field was critically examined. As a result, two basic wheel types were selected for further study, test and, evaluation as described in the following section.

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## SECTION II CANDIDATE WHEEL DESIGNS

Initially AC-DRL built and tested four breadboard wheels of two basic types. All four are 32 inches in diameter, with a 9-inch section width. All contain a rim, spun aluminum disc, and flexible woven-wire outer frame. One wheel is an open single mesh wire-frame design. The other three are various closed designs with fabric between double mesh. These breadboard wheels were designed for the Dual-Mode Lunar Surface Roving Vehicle (DLRV); the wheel design and construction were essentially the same as the Lunar Roving Vehicle (LRV) wheel, except for the nominal design load. Due to the similarity of LRV and DLRV wheel designs the conclusions resulting from the tests described later in this report are applicable to both DLRV and LRV wheel selection, even though the tests were performed on wheels designed for slightly different loads.

### 2.1 Open Wheel Design

The wheel concept shown in Figures 1 and 2 is a single-mesh, open wire frame design with herringbone tread. The wheel consists of a rim, disc, flexible woven wire outer frame, tread and necessary fasteners. The rim and disc are spun from 2024 aluminum alloy sheet. The disc and rim are then trimmed and heat treated. Figure 1 also shows an inner frame - this frame was not included in the breadboard wheels since it was not required for the tests being conducted. It is included in the deliverable wheels.

The flexible wire frame is woven from music spring wire consisting of 600 interwoven 0.032-inch-diameter wires in a 0.25-inch mesh. Each wire is crimped at fixed intervals by using a crimping machine. The crimped wires are then woven into a flat mesh and the ends of the mesh are interwoven to form a cylinder. The cylinder ends are clamped in a stress-relief fixture to form a torus which is then stress-relieved and removed from the fixture.

The tread strips are applied to the wire frame in a herringbone pattern. Each strip is secured to the woven wire by a rivet which passes through the tread strip and the wire mesh and is headed over a washer on the back side of the mesh. A tubular spacer between the tread strip and the securing washer prevents clamping of the wire mesh.

### 2.2 Closed Wheel Design

Several configurations of closed wheels were proposed and three different configurations were built and tested.





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Figure 2 Open Wheel Design

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2.2.1 Fully Enclosed, One Piece Pleated Fabric. The wheel configuration shown in Figures 3 and 4 is a double-mesh, closed wire-frame design with cleats. This design is identical to the open wheel except for the outer frame and tread; again the inner frame was not installed on the breadboard wheels. For a breadboard wheel the flexible outer frame consists of two layers each of 600 interwoven 0.027-inch-diameter wires in a 0.25-in. mesh with a high-strength fabric coated with teflon (DuPont Armalon) sandwiched between the two providing a completely enclosed wheel to us. The fabric was folded to conform to the wheel contour. Radial and peripheral folds were made in the fabric of sufficient depth to allow the wheel to deflect without overstressing the fabric in tension. The woven wire meshes were fabricated of .027" zinc-cadmium coated music wire. The coating process was accomplished during the drawing of the wire. A separate tread over the wire frame mesh is not required, but bottle cap type cleats are provided to increase traction over surfaces with a low coefficient of friction. The assembly process is the same as for the open-frame wheel.

2.2.2 Fully Enclosed Woven Fabric. The wheel configuration shown in Figure 5 is a double-mesh fully enclosed wire-frame design with cleats. This design evolved after a tear developed in the fully enclosed wheel described above during soil bin tests and was an attempt to provide a fully enclosed wheel that would withstand the fatigue, wear and stresses on the fabric. This design is identical to the fully enclosed one-piece pleated fabric design except that the fabric closure is woven from strips of the DuPont Armalon. To complete this wheel in a minimum of time, two woven wire meshes which had previously been rejected for weaving and wire imperfections were used. The inner mesh was made of the .027" diameter and the outer of .032" diameter zinc-cadmium wire as above. This wheel was also assembled with bottle cap type cleats.

2.2.3 Semi-enclosed Overlapping Fabric. The wheel configuration shown in Figure 6 is a double-mesh semi-enclosed wire-frame design with cleats. This design is identical to the fully enclosed design except the enclosure consists of strips of fabric that overlap, covering only the bearing surface of the wheel and a portion of the wheel sides. This wheel design was developed in an attempt to combine the desirable qualities of the closed and open wheels. The two meshes used in this wheel were disassembled from the fully enclosed wheel described in paragraph 2.2.1 above. The fabric was cut essentially into strips and placed at an angle across the contour of the inner mesh. Each strip overlapped the previous strip to form a closed cover at the periphery.

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### 2.3 Weight Comparison

A summary weight comparison, Table I, is included as an important criterion for eventual candidate selection. The weights given are for the complete wheels including the inner frame.

Table I  
WEIGHT COMPARISON

Component	Candidate Wheels			
	Open*	Closed		
		One Piece Pleated	Woven	Overlapped Semiclosed
Outer Frame	6.14	6.68	7.48	6.20
Inner Frame	3.86	3.86	3.86	3.86
Wheel Rim and Disc and Hub	2.10	2.10	2.10	2.10
Hardware	0.44	0.44	0.44	0.44
TOTAL	12.54 lb	13.08 lb	13.88 lb	12.60 lb

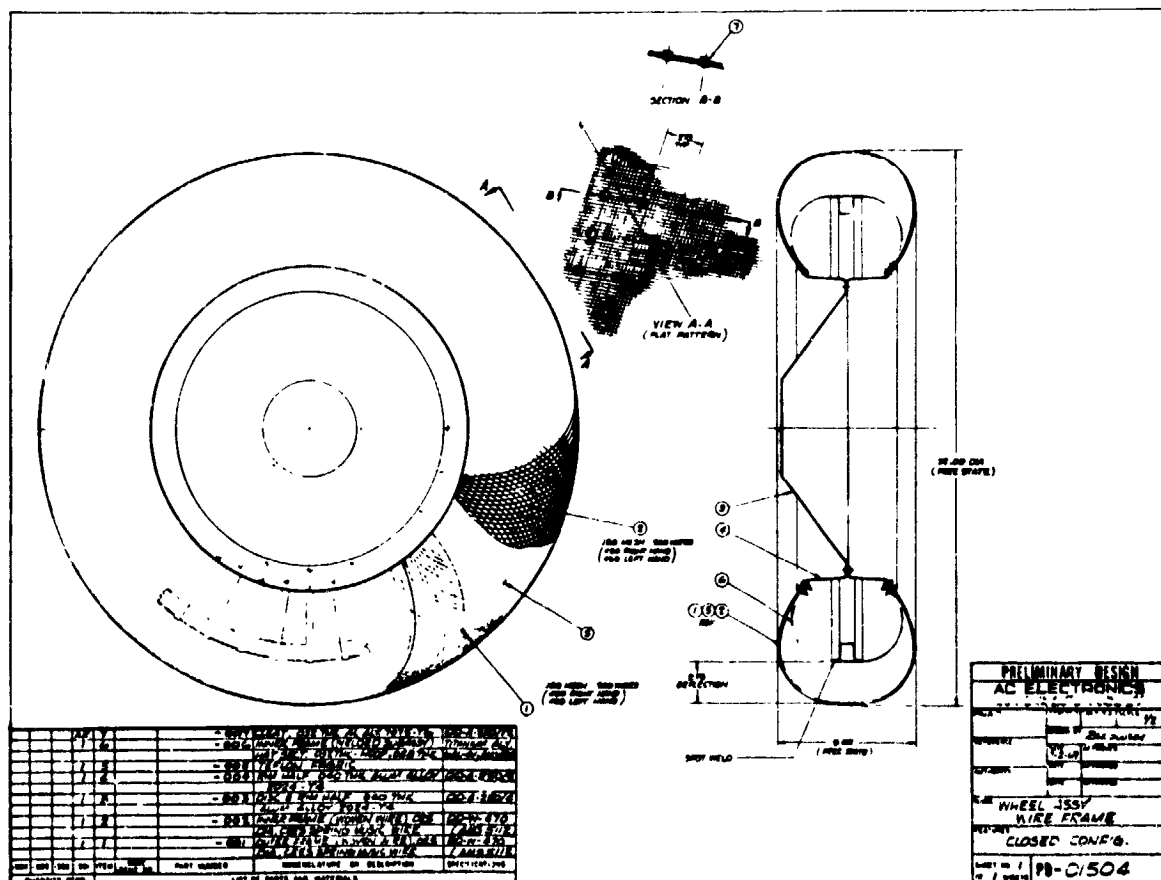


Figure 3 Wire-Frame Wheel, One-Piece Closed Configuration

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Figure 4 Fully Enclosed, One-Piece Pleated Fabric Design

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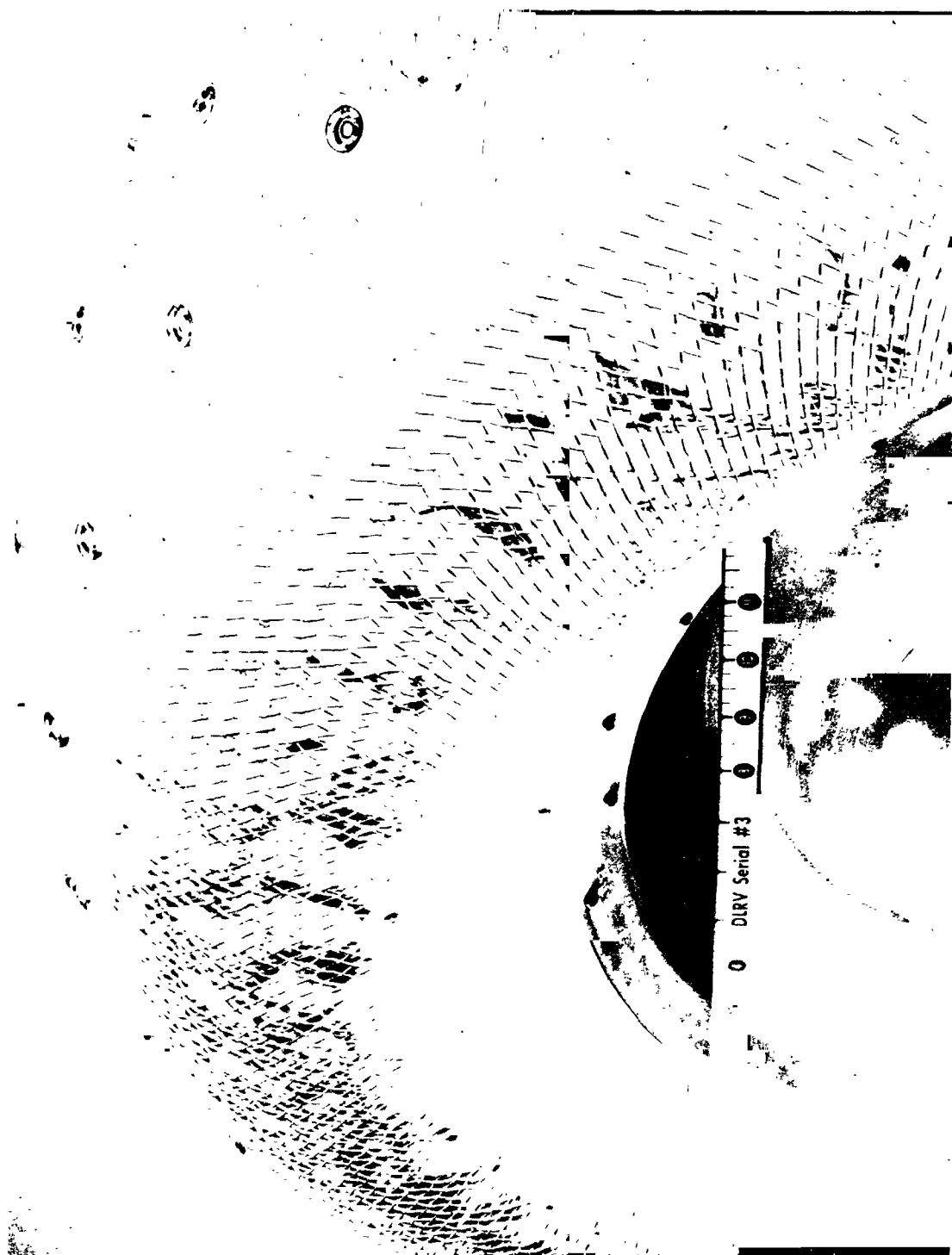


Figure 5 Fully Enclosed Woven Fabric Design

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Figure 6 Semi-Enclosed Overlapping Fabric Design

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## SECTION III TEST OBJECTIVES

### 3.1 Purpose

The purpose of the following tests performed on breadboard AC-DRL DLRV wire frame wheel candidates was to help select the final DLRV wheel concept and verify engineering analyses. The tests were performed by AC-DRL at General Motors Corporation facilities.

### 3.2 Objective

The objective of the tests was to provide data for final wheel selection.

#### 3.2.1 Soft Soil Mobility Studies:

1. To measure the tractive performance of each wheel candidate.
2. To determine the motion resistance of each wheel candidate.

These tests determined the ability of each wheel candidate to function in soft soils and to meet the 25 degree slope gradability required.

3.2.2 Mechanical Tests. Load deflection studies, to determine the spring rate characteristics of the breadboard wheels in the three primary axes.

#### 3.2.3 Endurance Tests:

1. Smooth road endurance tests, to determine the endurance of candidate wheels for extensive smooth surface travel.
2. Random obstacle endurance tests, to determine the endurance limit of the candidate wheels for extensive travel over random obstacles.

These tests determined the ability of each wheel candidate to meet engineering and mission profile requirements.

## SECTION IV CANDIDATE WHEEL TESTING

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### 4.1 Soft Soil Tests

4.1.1 Scope of Test. Soft soil tests were performed at the General Motors Soil Bin Facility on both the open wheel and the fully enclosed, one piece, pleated fabric wheel to determine the soft soil mobility characteristics of the two basic designs. The tests determined, for various loads, drawbar-pull and thrust vs slip as well as motion resistance for each wheel design. The tests were conducted in air dry, crushed silica sand for the two conditions specified in Table II. The "Land Locomotion Soil Values" were determined by Bevameter Shear and Penetrometer Devices. The soil angle of friction  $\phi$  and cohesion  $c$  were also determined from shear box tests. Examples of the recorded soil characteristics are shown in Appendix 1.

Table II  
SOIL DATA

Soil Factor	Crushed Silica Sand, Air Dry	
	Loose Condition	Compacted Condition
Bevameter $\phi$ peak	$34^{\circ} \pm 3^{\circ}$	$40^{\circ} \pm 2^{\circ}$
Bevameter $\phi$ ultimate	$34^{\circ} \pm 3^{\circ}$	$34^{\circ} \pm 3^{\circ}$
Bevameter $c$	0 psi	0 psi
$k_{\phi}$	$4.0 \pm 0.6 \text{ lb/in.}^{n+2}$	$10 \pm 2 \text{ lb/in.}^{n+2}$
$k_c$	$0 \text{ lb/in.}^{n+1}$	$0 \text{ lb/in.}^{n+1}$
$n$	0.8	0.6
$K$	0.40 in.	0.35 in.
$\gamma$	$97 \pm 3 \text{ lb/ft}^3$	$107 \pm 2 \text{ lb/ft}^3$
Moisture Content	0.5%	0.5%
Shear Box $\phi$ peak	$35.3^{\circ}$	$40.8^{\circ}$
Shear Box $\phi$ ultimate	$34.9^{\circ}$	$33.8^{\circ}$
Shear Box $c$	0	0

**Abstract —** The tests showed that both wheel designs met the 25 degree slope gradability requirement. However, in the loose soil the covered wheel performed from 10% to 15% better at slips over 20%. In the compacted soil there was no statistical difference between the wheels. The covered wheel incurred a failure in the Armalon cover half way through the soft soil tests. This failure was in the form of a circumferential rip.



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#### 4.1.2 Administrative Data

Test Condition – The tests were supervised by personnel of the AC-DRL Lunar Systems Department. They were run in the General Motors Soil Bin Facility at Hudson, Ohio, by the soil bin facility personnel.

Test Dates – The tests on the open wheel were run during December 18, 19, and 22, 1969. The tests on the closed wheel were run during January 7, 8, and 9, 1970.

The Test Samples – The tests were run on the wheels described in paragraphs 2.1 and 2.2.1, the open and the fully enclosed, one piece pleated fabric designs.

Test Facilities – The test facilities and equipment required to perform the tests specified herein are listed in Table III and described as follows:

Soil Bin and Associated Equipment – The GM soil bin facility is 40 ft long with a soil section 60 in. wide and 30 in. deep. The rail-mounted test carriage provides mounting for wheels up to 48 in. diameter under loads of up to 2000 lb at speeds of 1 to 4 fps and up to 1000 lb at 1 to 10 fps. A variable speed AC drive system is used to propel, brake, and control the carriage. (See Figure 7.)

Table III  
TEST EQUIPMENT

(1)	Large Soil Bin
(2)	Soil Bin Test Carriage Including:
	(a) Two-Axis Load Cell Dynamometer
	(b) Wheel Torque Cell
	(c) Sinkage Potentiometer
	(d) Carriage Travel Potentiometer
	(e) Wheel Revolution Counter
	(f) Bevameter Soil Test Device
(3)	Recording Equipment
(4)	Weights
(5)	Work Car Including:
	(a) Tiller
	(b) Leveling Blade
	(c) Compactor

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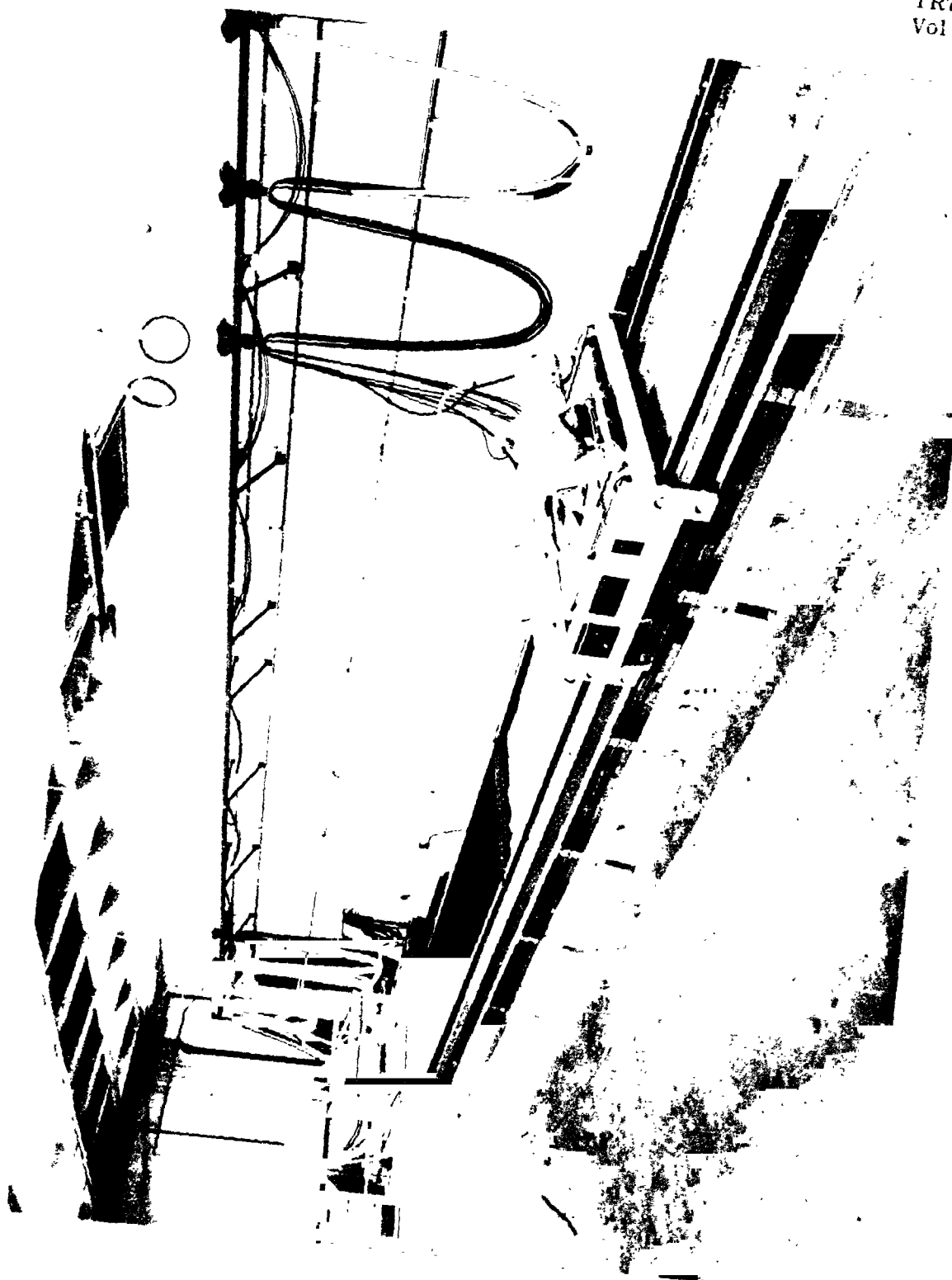


Figure 7 GM Soil Bin

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Test Requirements – The tests were run in accordance with the following procedure.

Drawbar-Pull and Thrust vs Slip Tests – Drawbar-pull and thrust vs slip tests were conducted on the test articles in each of the soils described in paragraph 4. 1. 1. The test sequence consisted of:

1. Soil Preparation – Prior to the start of each test the soil was tilled and leveled by using the soil bin work car.
2. Measurement of Soil Parameters – Before, during and at completion of each day's testing, two penetration and one shear test were conducted at three locations in the soil bin by using the Benvameter soil test device mounted on the test carriage. Values of the pertinent soil parameters were determined from the test data.
3. Data Runs – Drawbar-pull/thrust vs slip tests were conducted at normal wheel loads of 30, 45 and 60 lb. Each test run was repeated at least once or as many times as required to obtain reasonable agreement between test data from consecutive runs. The wheel and test carriage were started at a predetermined synchronous speed (0 slip condition) and the speed of the test carriage was decreased in a continuous manner to 0 speed with the wheel speed held constant (100% slip condition). Drawbar-pull, wheel torque, wheel sinkage, revolutions, and normal load were recorded on a strip chart recorder (see Figure 8 for example).

Motion Resistance Tests – Motion resistance tests were conducted during selected runs in each of the soils described. To perform the motion resistance test, the carriage was run at constant speed for the full length of the soil bin with the wheel in a free-wheeling mode (drive chain detached). Motion resistance, wheel revolutions, carriage travel, normal load, and wheel sinkage were recorded. Soil preparation and measurement of soil parameters were identical to the procedure described above for drawbar-pull tests.

Disposition of Test Samples – After completion of tests, the test articles were returned to AC-DRL for the conductance of Endurance Tests.

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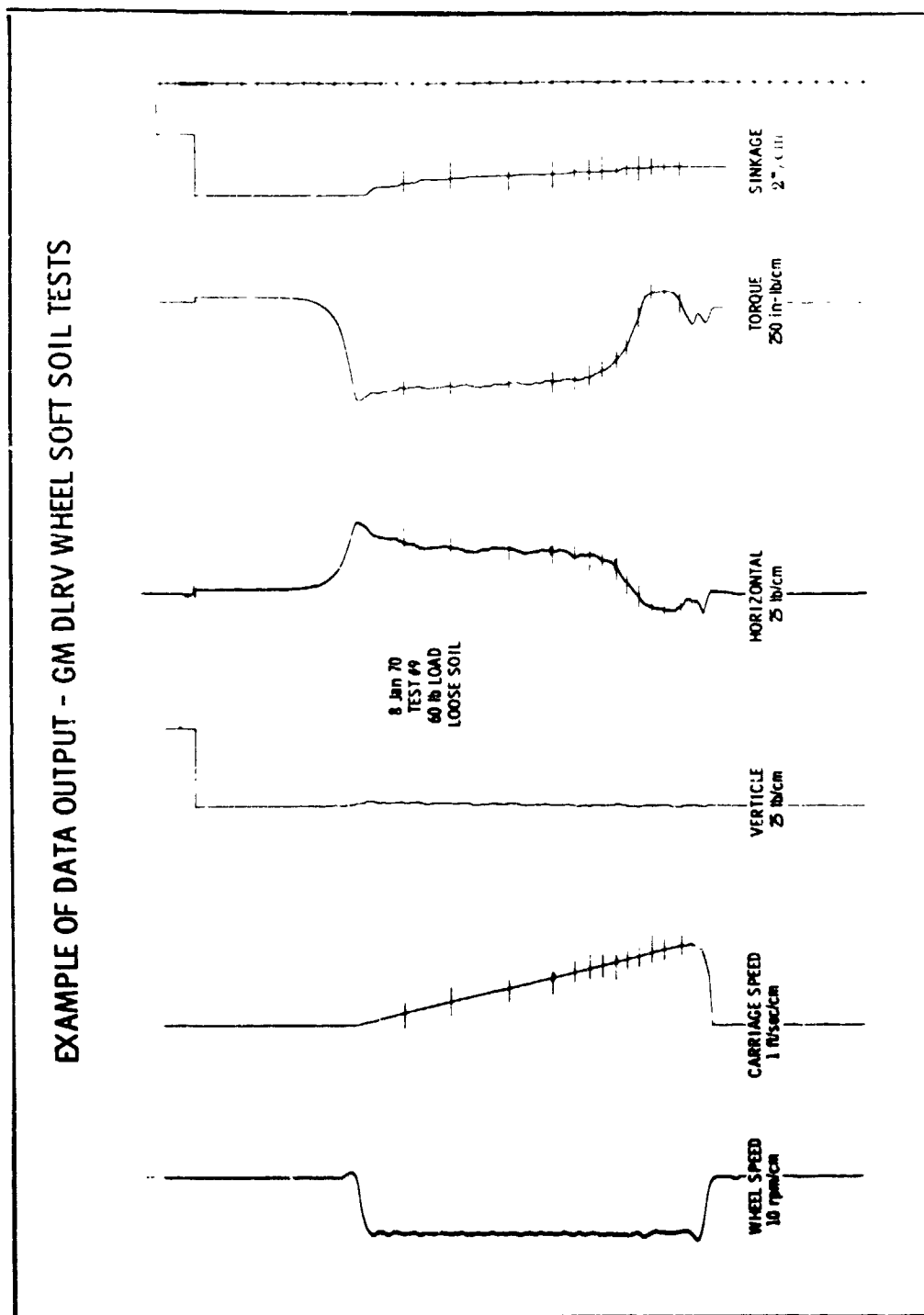


Figure 8 Typical Recorder Output for Soil Bin Tests

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**4.1.3 Test History and Results.** The first series of tests was on the open wheel design, the second series on the closed wheel design. The following sequence was followed for both series of tests:

- a. Calibration of Equipment – Sample calibration sheets are reproduced in Appendix 2.
- b. Soil Tests – The soil was tested at the beginning and end of each day of testing and at intermediate times such as when soil conditions were changed. This occurred during both the first and second series of tests. (Samples in Appendix 1).
- c. Drawbar-pull and thrust tests at various loads – The wheel was drawn through the soil at a continuously decreasing speed while the wheel revolutions per minute were kept constant. This produced a varying slip from -20% to +100%. The wheel sinkage, torque, horizontal force, load or vertical force, carriage speed, and wheel speed were continuously recorded on a strip chart recorder. A typical recorder output is shown in Figure 8. These tests were repeated for wheel loads of 30 lb, 45 lb, and 60 lb. Results of these tests were plotted and the plots are reproduced in Appendix 3 for the open wheel and Appendix 4 for the closed wheel. Summaries of the test results are presented in section 4.1.4. The tests were first run in the loose soil condition and then repeated in the compacted soil condition.
- d. Motion Resistance Tests – The motion resistance tests were run after the drawbar-pull tests, first in compacted soil and then in loose soil.
- e. Radius – The effective rolling radius was determined for both wheel designs by pulling the undriven wheels until they had made 4 revolutions, then measuring the distance traveled and determining the effective radius. The results are shown in Figure 9 for both wheels and both soil conditions.

In addition to the prescribed tests, a series of special tests was run on the closed wheel to check the accuracy and calibration of the test equipment.

**Special Equipment Tests** – The recording equipment was checked by pulling on the carriage with a known force and checking the readings on the strip chart recorder.

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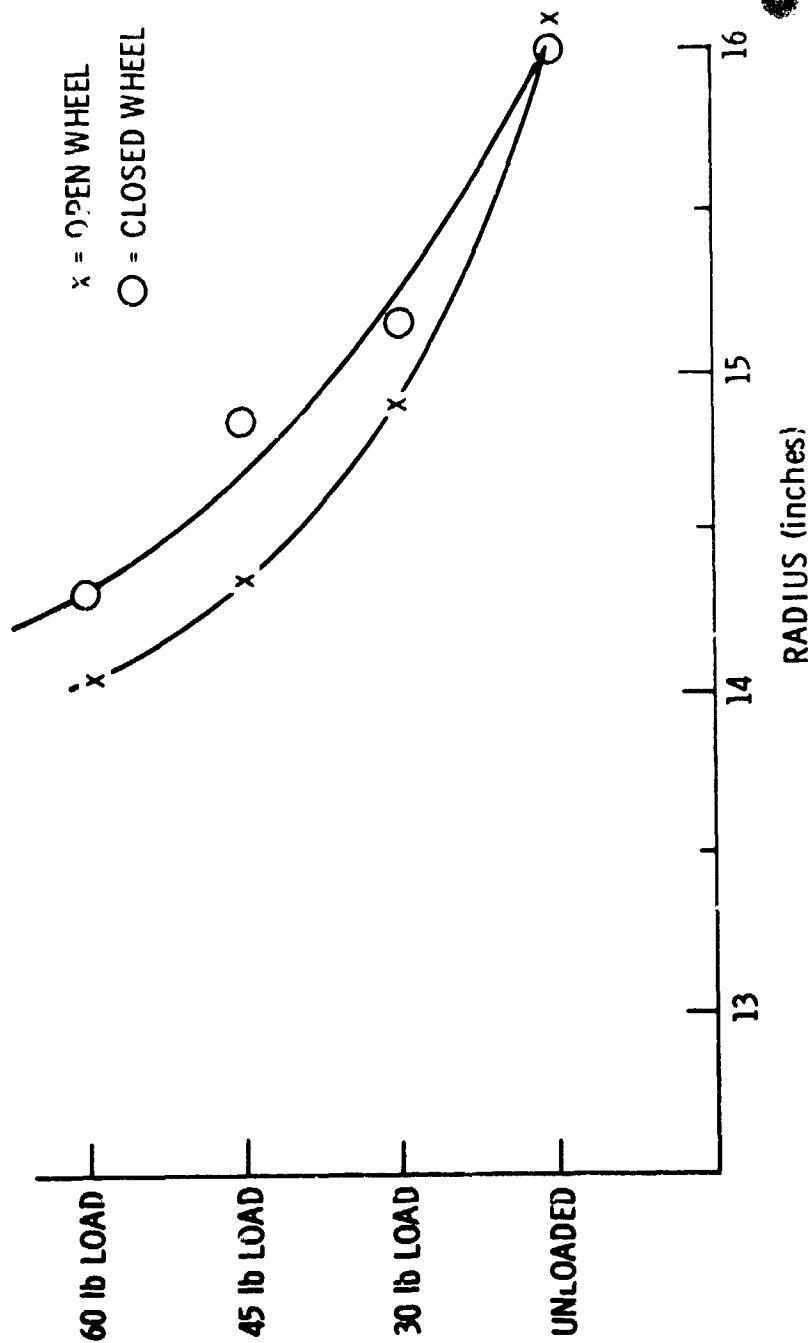


Figure 9 Effective Radius of Rolling Wheels, Crushed Silica Sand, Air Dry, Loose and Compacted Soils

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Also a full test was run with the wheel operating out of the soil. This test was conducted to see if the deceleration of the carriage provides a drawbar pull due to "MA" forces, i. e., an indicated drawbar pull due to the change in carriage velocity and its mass. The strip chart is reproduced in Figure 10; the drawbar pull is shown on the chart as the line labeled Horizontal Force. After the original jerk of starting the carriage, it can be seen that "MA" forces do not significantly contribute to the drawbar pull. A zero force on the chart is the steady line below the jerk and a positive pull is a deviation to the right of this steady state zero line. Finally, the drawbar pull test was repeated at a constant slip and a 45 lb load. This was done by applying a 45 lb load and a known rpm to the wheel and then pulling the carriage at a constant speed so that a positive slip would occur. The results were within the  $\pm 2\sigma$  for the 45 lb varying carriage speed tests. Again this test indicates that the carriage does not add a false drawbar pull to the wheel's capability.

**4.1.4 Summary Test Data.** The test results were summarized in several different ways to analyze the performance of each wheel design.

**Theoretical and Actual Wheel Performance** – The "Land Locomotion Soil Values" for the crushed silica sand, air dry, loose condition (in which the tests were run) were utilized along with each wheel's characteristics and various loads to determine theoretical drawbar pull. This was done by using a computer program which estimated P/W based on soil characteristics, the load, and wheel parameters. The P/W vs slip results of this program were plotted. Also, on the same graph was plotted the 25 degree slope gradability line. Finally on the same graph were plotted curves obtained by computer regression analysis of the data recorded during soft soil tests. Figures 11 and 12 show results for both wheels at the 60 lb load. It can be seen that the actual performance and predicted performance in the test soil and the NASA soil are comparable, and that the 25 degree gradability requirement has been met. The actual data for Figure 12 fit a curve specified by

$$P/W = -0.017 + 0.052S - 0.002S^2 + (0.22)(10^{-4})S^3 - (0.10)(10^{-6})S^4$$

(S = slip in %)

For the comparison of predicted P/W values for GM and NASA specified soils the following values shown in Table IV were used.

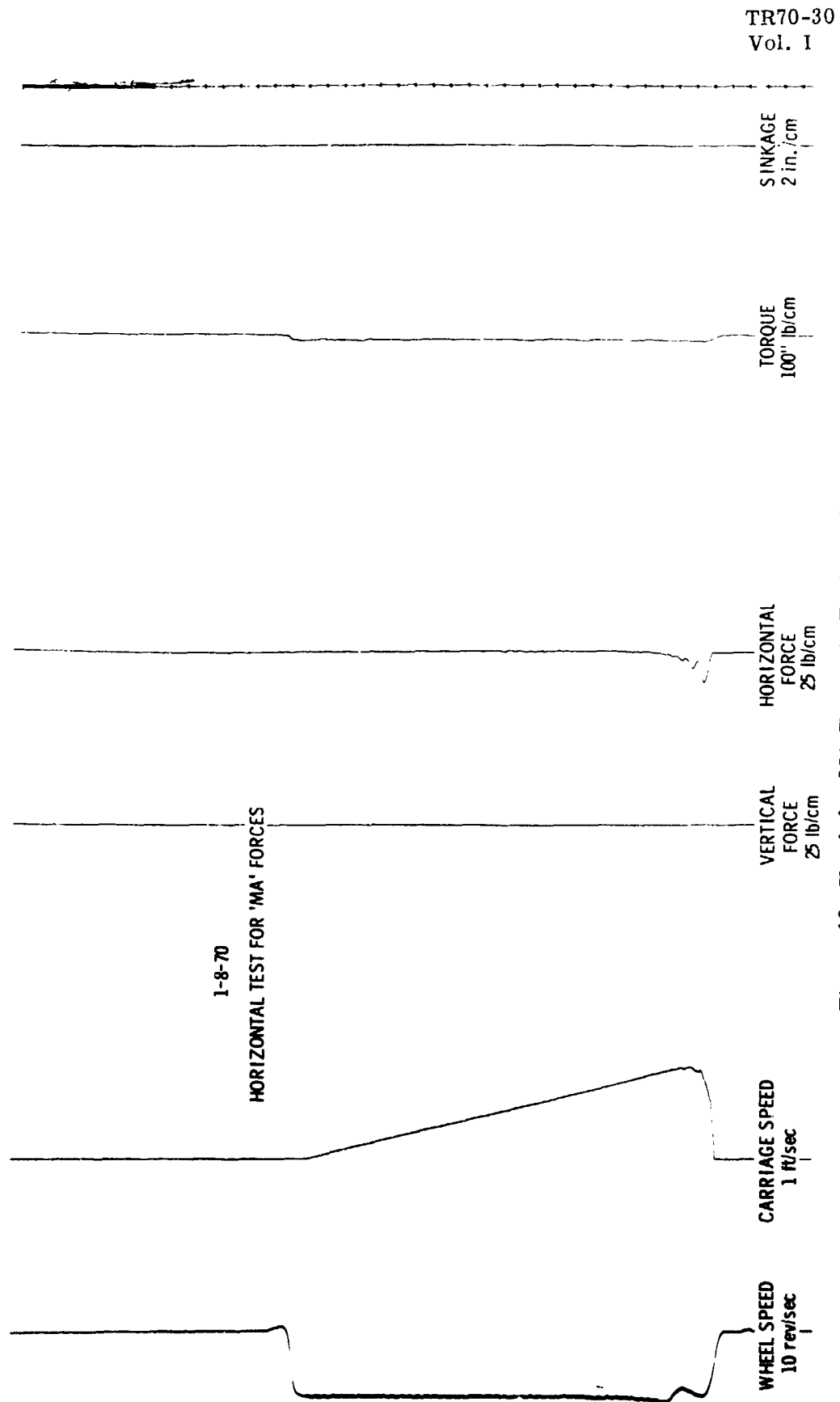


Figure 10 Check for MA Forces in Equipment



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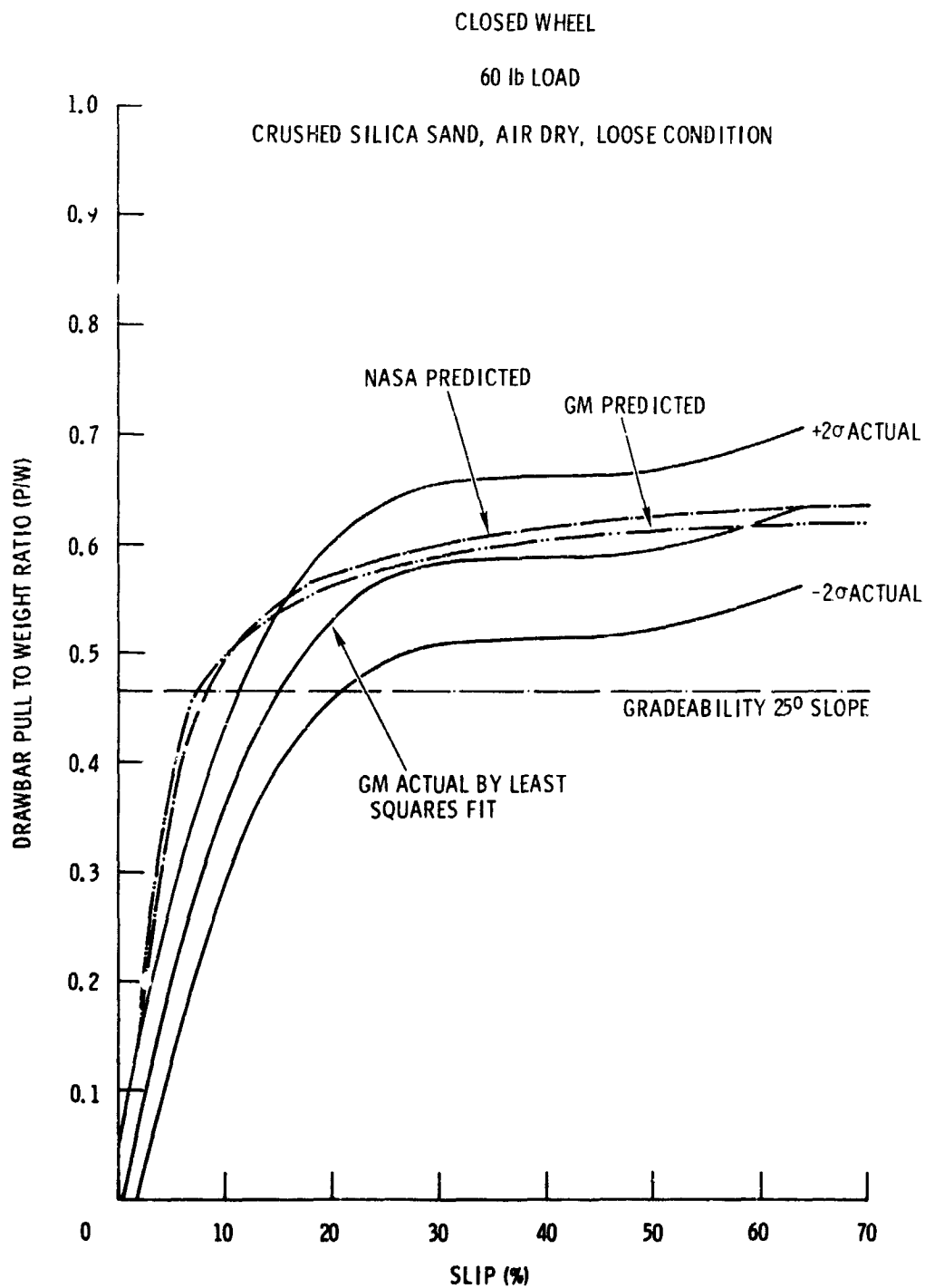


Figure 11 One-Piece Closed Configuration – Comparison of Predicted and Actual P/W

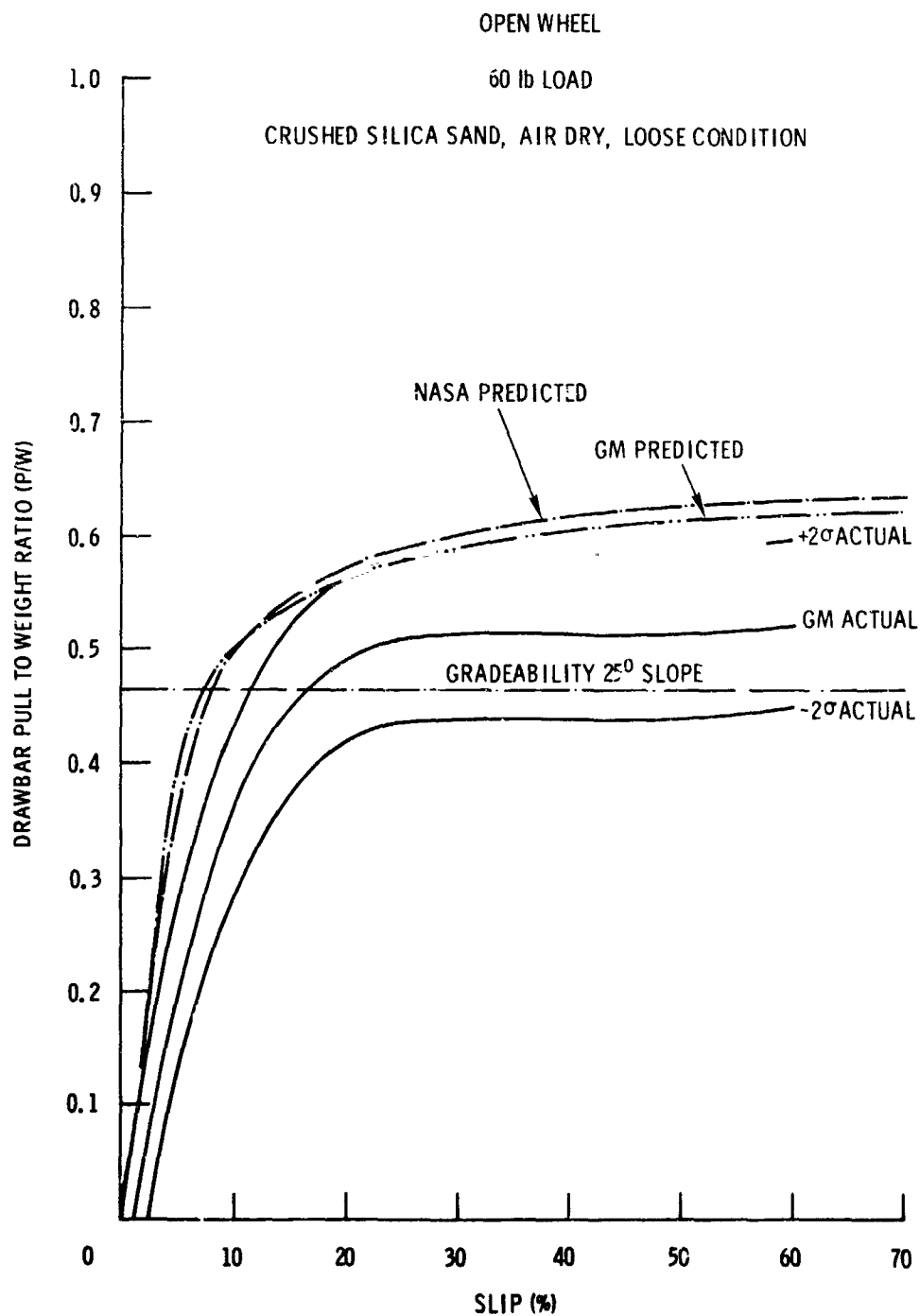
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Figure 12 Open Configuration - Comparison of Predicted and Actual P/W

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Table IV  
NASA SPECIFIED VALUES AND GM SOIL BIN VALUES

Values	$k_{\phi}$ lb/in. <sup>n+2</sup>	$k_c$ lb/in. <sup>n+1</sup>	n	$\phi$ Deg	c psi	K in.	$\gamma$ lb/in. <sup>3</sup>
NASA Specified Values	3.0	0.0	1.0	35.0	0.0	0.4	0.05
GM Soil Bin Values	4.0	0.0	0.8	34.0	0.0	0.4	0.06

Difference in wheels -- To see if the different wheel designs produced different draw-bar pull, all the results for a 60 lb wheel load in both soil conditions were plotted on the same graph and the area in which they fell was shaded (Figures 13 and 14). It can be seen that a difference does exist in loose sand and the closed wheel performs better. However, in compacted sand there is no difference in performance.

P/W versus M/ReW (1-S) -- To obtain a comparison of the wheels in terms of an energy factor, P/W was plotted versus M/ReW(1-S), a dimensionless measure of the energy required to drive the wheel. These plots are reproduced in Figures 15, 16, and 17 for 60 lb and 45 lb loads in loose soil and 60 lb load in compacted soil. Again, a difference in wheel performance can be noted in loose soil but not in compacted soil. For the 60 lb wheel load the extra energy required to flex the two sets of wires and fabric of the closed configuration can be seen.

Composite results by load and soil condition -- For comparison purposes, the closed wheel and open wheel composite results for each load and soil condition are shown in Figures 18 to 23. Again, for the 30 lb and 45 lb loads the closed wheel performs better in loose soil but no appreciable difference exists in the compacted soils.

**4.1.5 Unplanned Events--Fabric Failure--** The fabric on the Fully Enclosed, One Piece Pleated Fabric Design failed halfway through soft soil testing, after approximately 3500 ft. The failure occurred as a split down the centerline of the wheel. At the completion of soil testing, the split was approximately 20 inches long (see Figure 24). This split occurred along a crease formed in the fabric when it was pleated to provide give during wheel deflection under load. At this time it is felt that the crease caused by pleating the fabric broke or weakened the glass fibers, thereby reducing their strength and causing eventual failure under tensile load.

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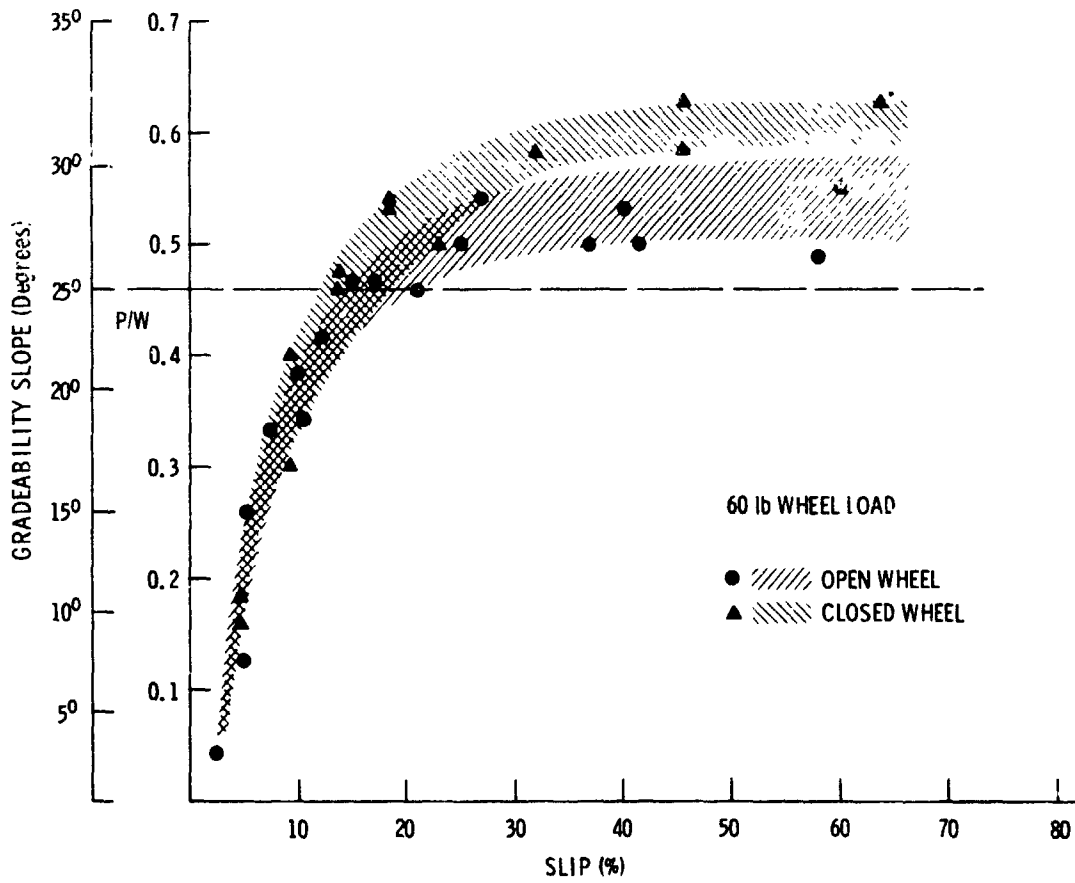


Figure 13 Drawbar Pull vs Slip: Crushed Silica Sand, Air Dry, Loose Condition

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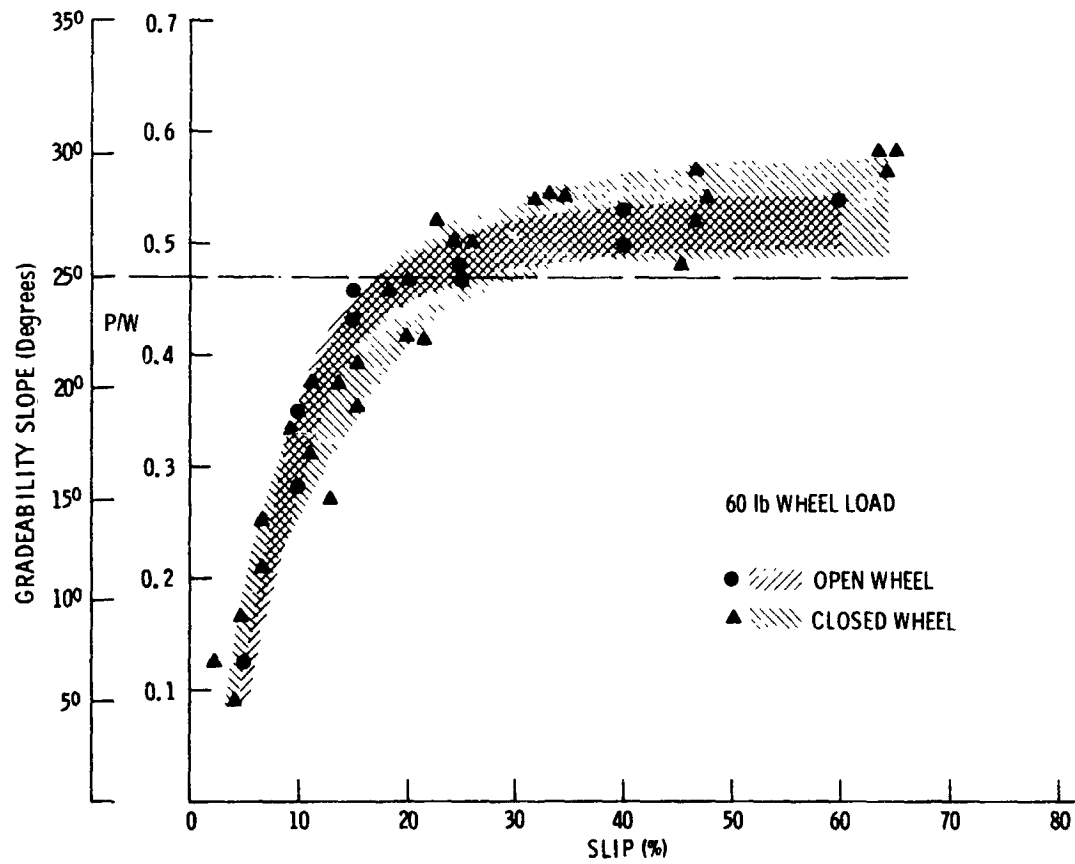
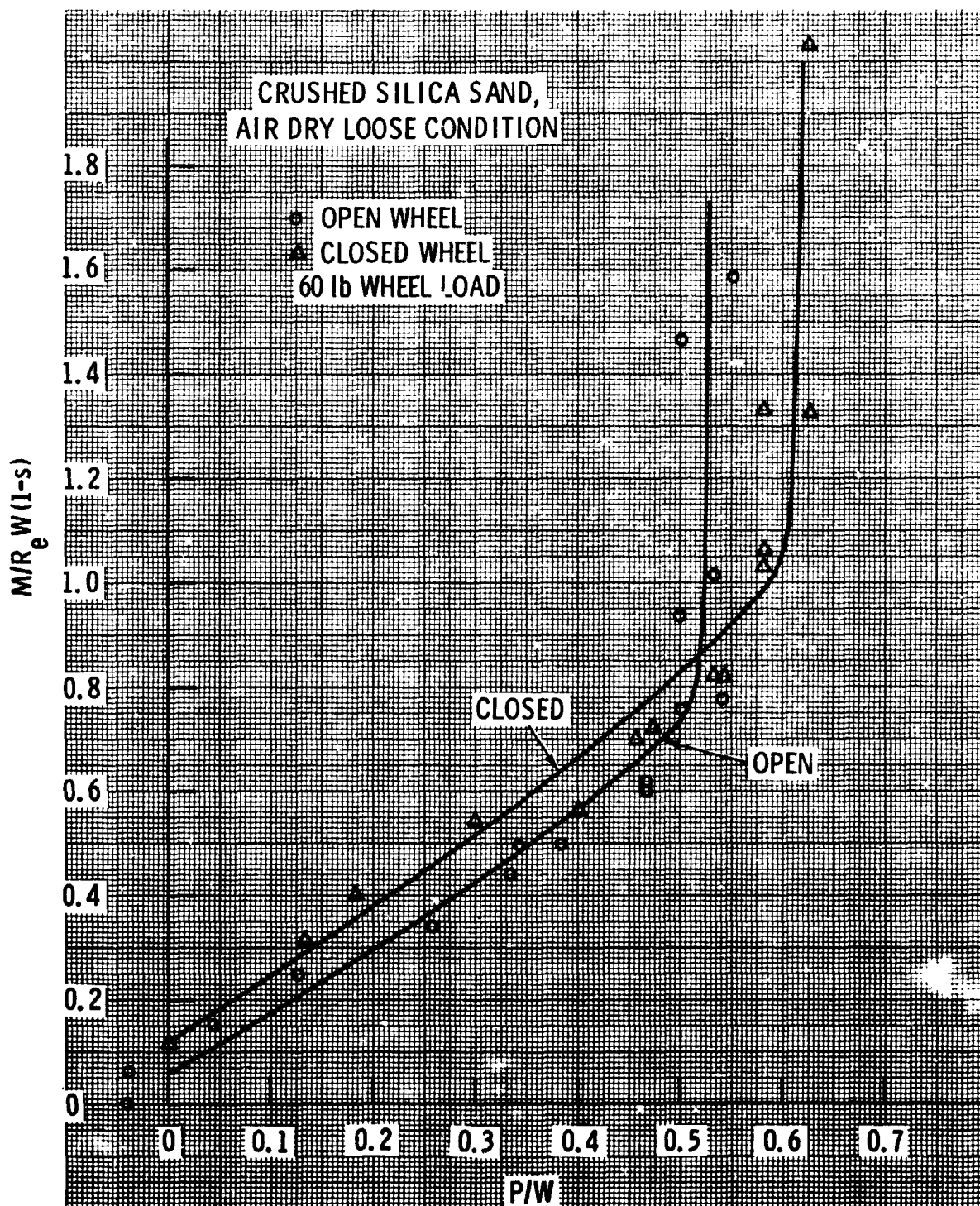


Figure 14 Drawbar Pull vs Slip: Crushed Silica Sand, Air Dry, Compacted Condition

Figure 15 Power Number vs  $P/W$ , 60 lb Load, Loose Soil Condition

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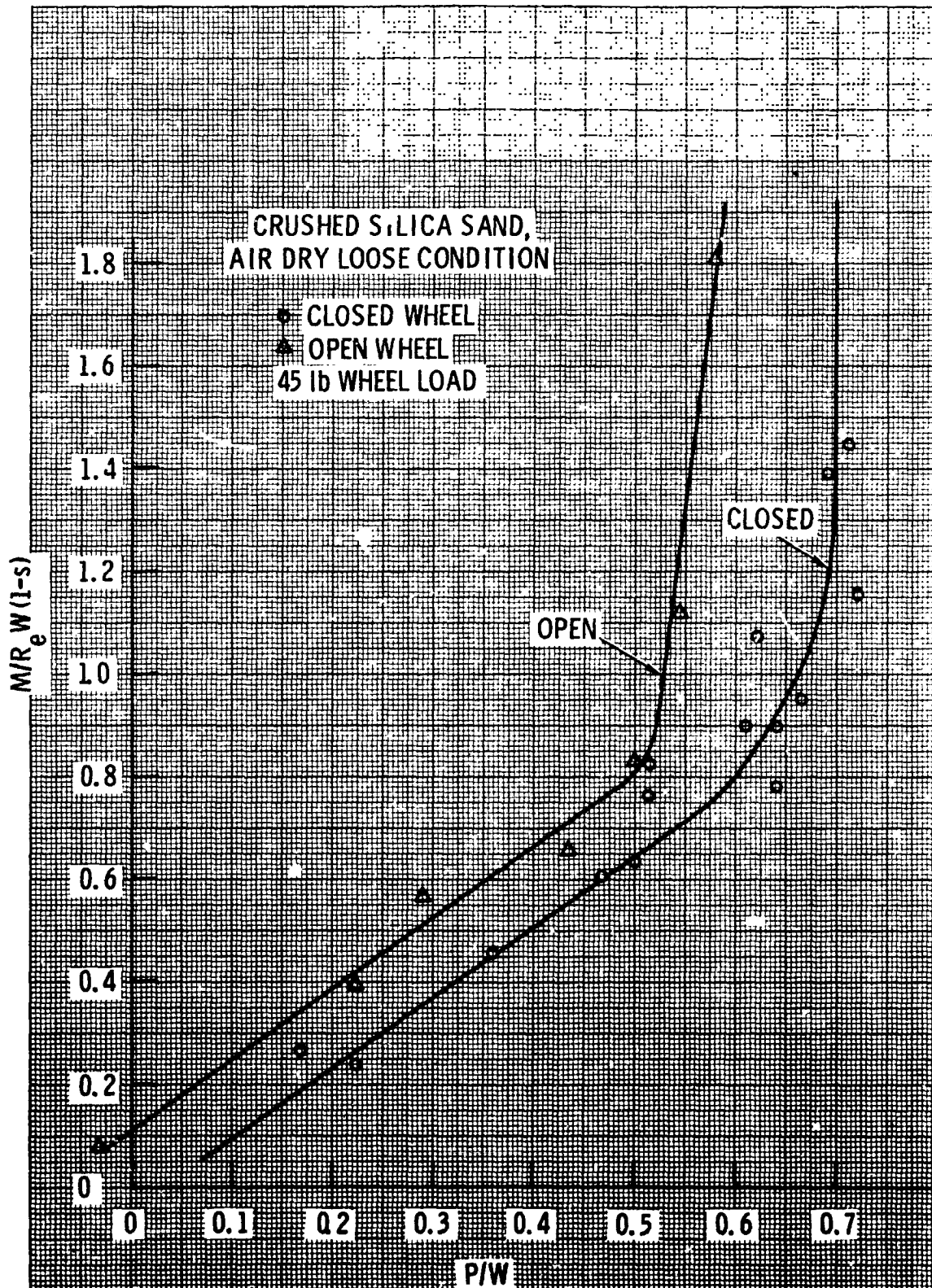
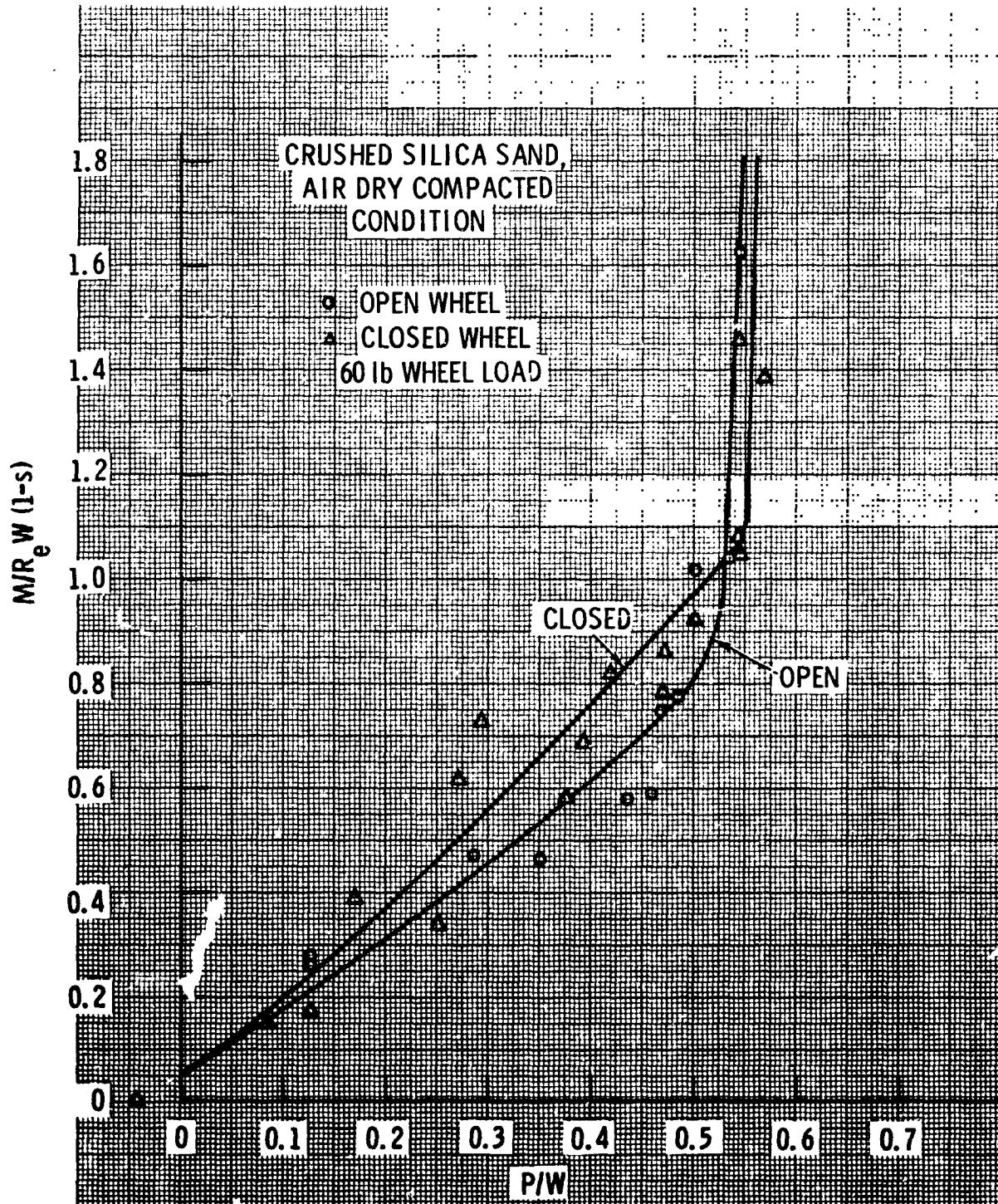


Figure 16 Power Number vs P/W, 45 lb Load, Loose Soil Condition

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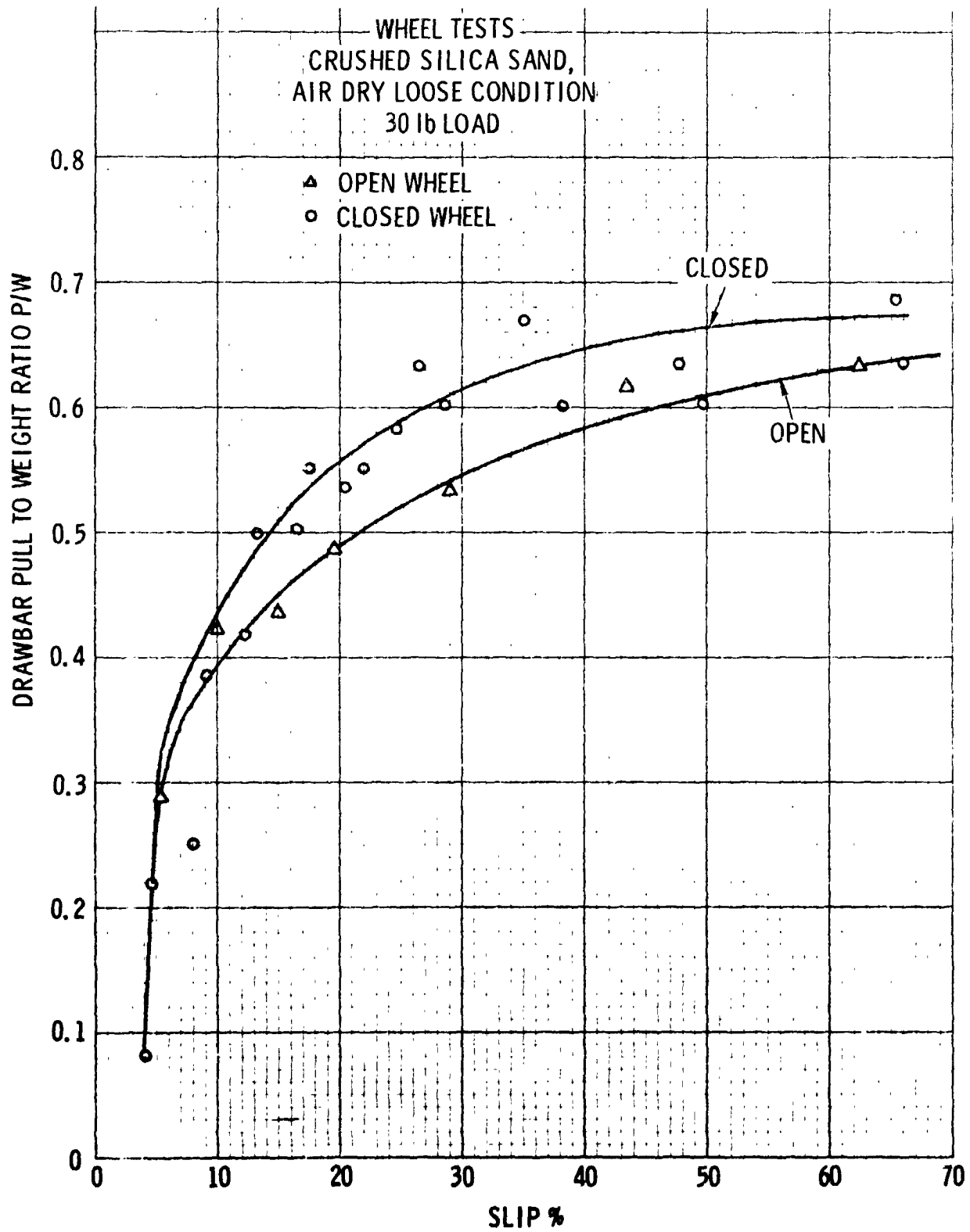


Figure 18 P/W vs Slip, 30 lb Load Summary, Loose Soil Condition

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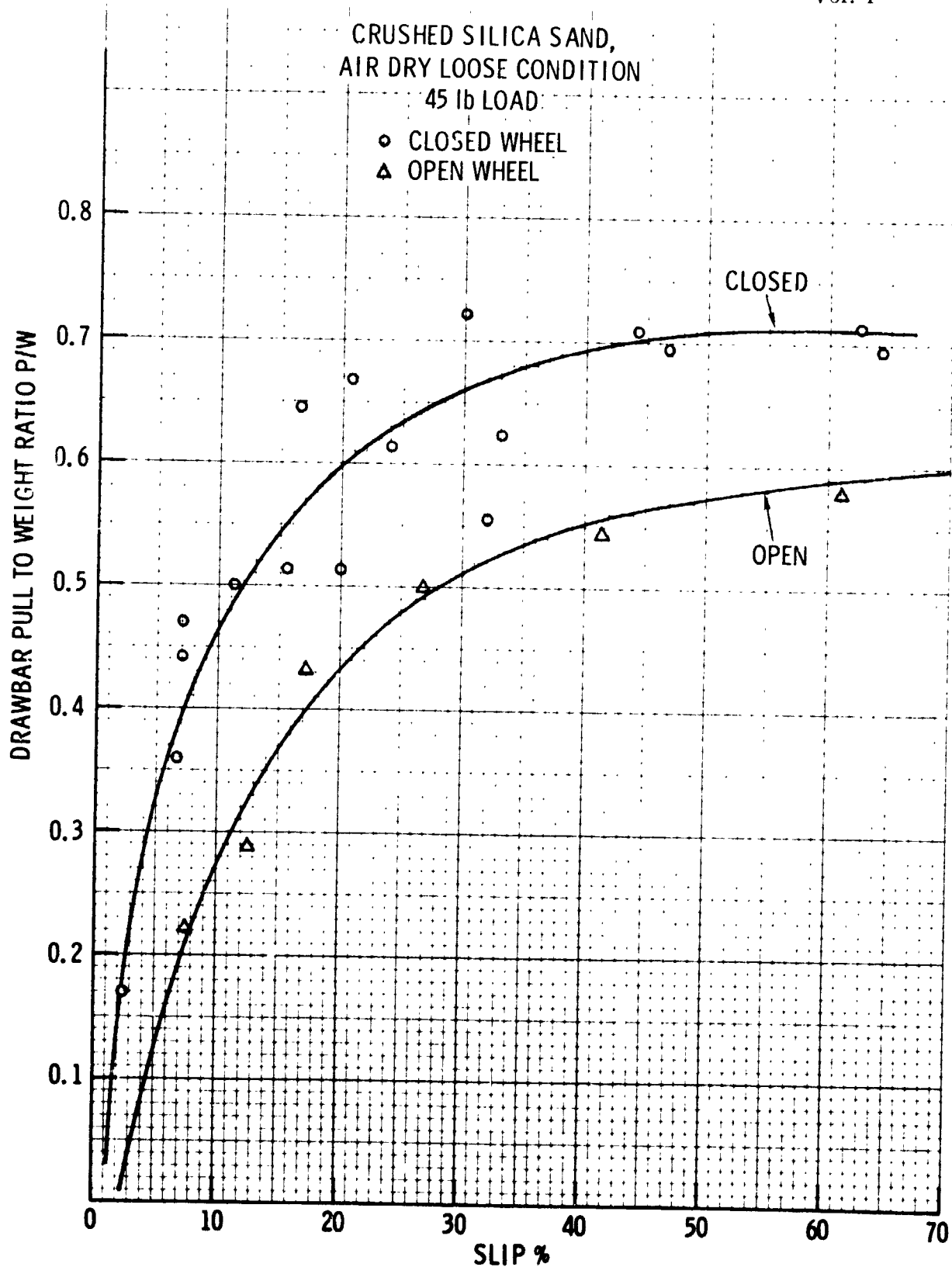


Figure 19 P/W vs Slip, 45 lb Load Summary, Loose Soil Condition

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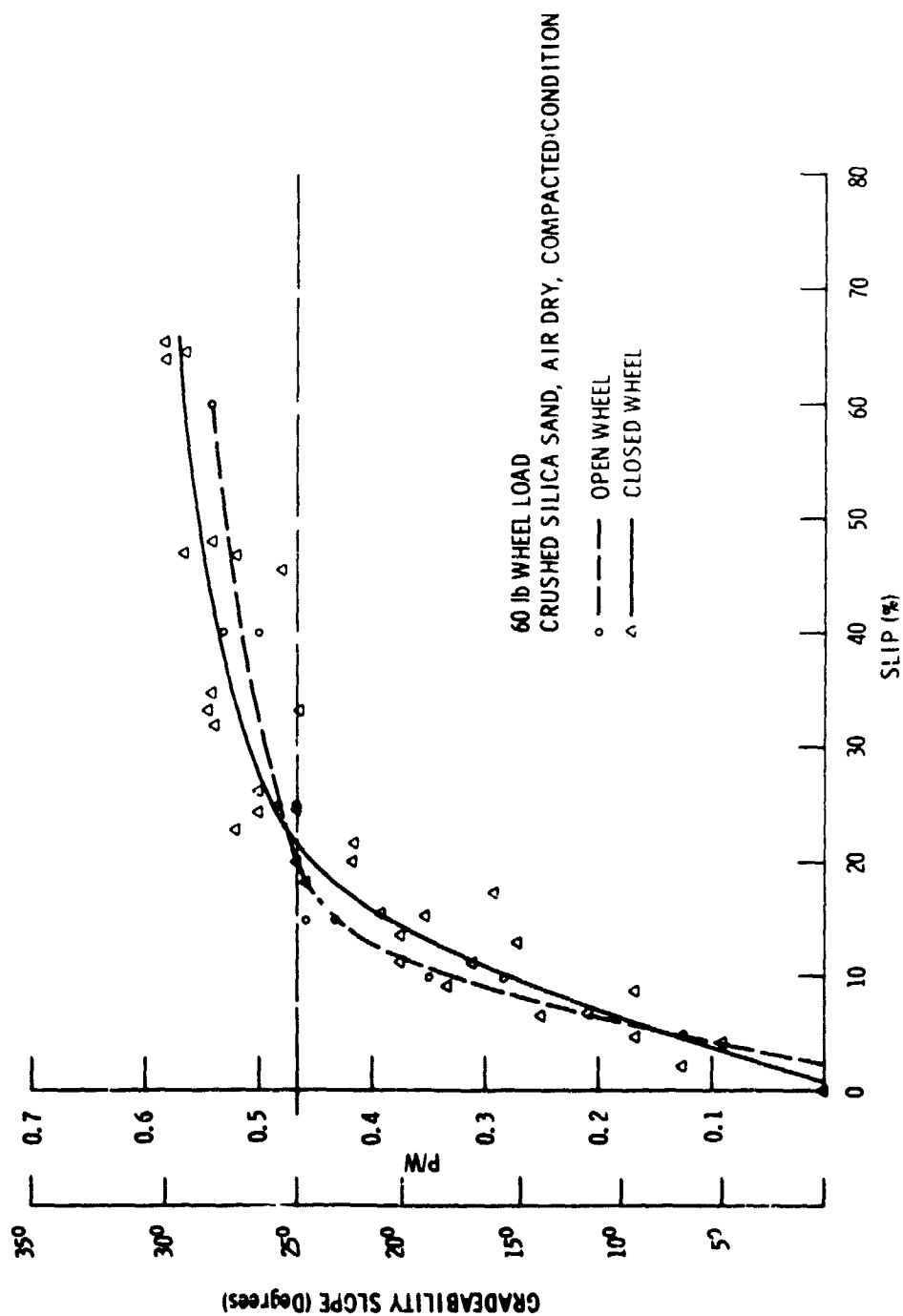


Figure 20 F/W vs Slip, 60 lb Load Summary, Loose Soil Condition

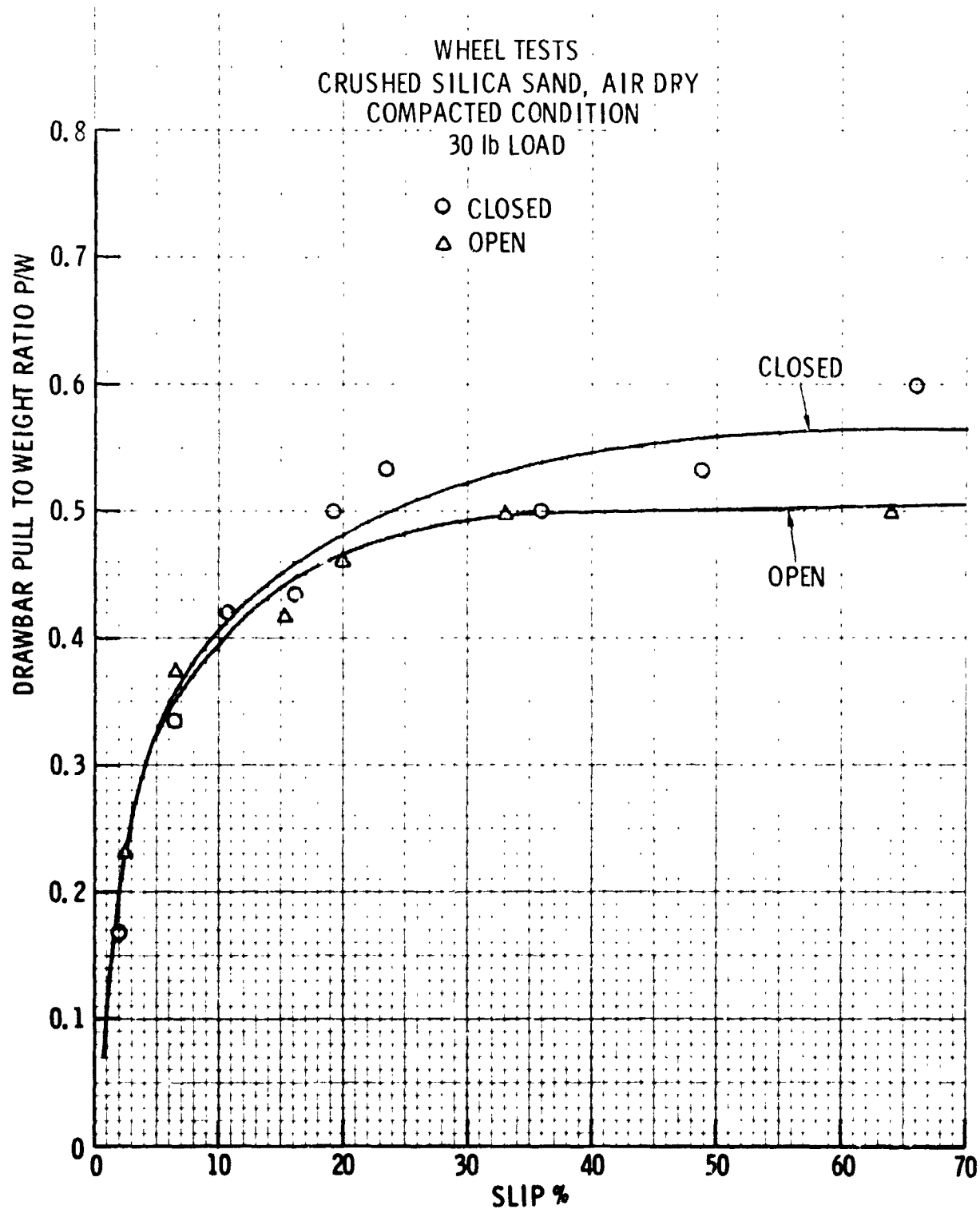
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Figure 21 P/W vs Slip, 30 lb Load Summary, Compacted Soil Condition

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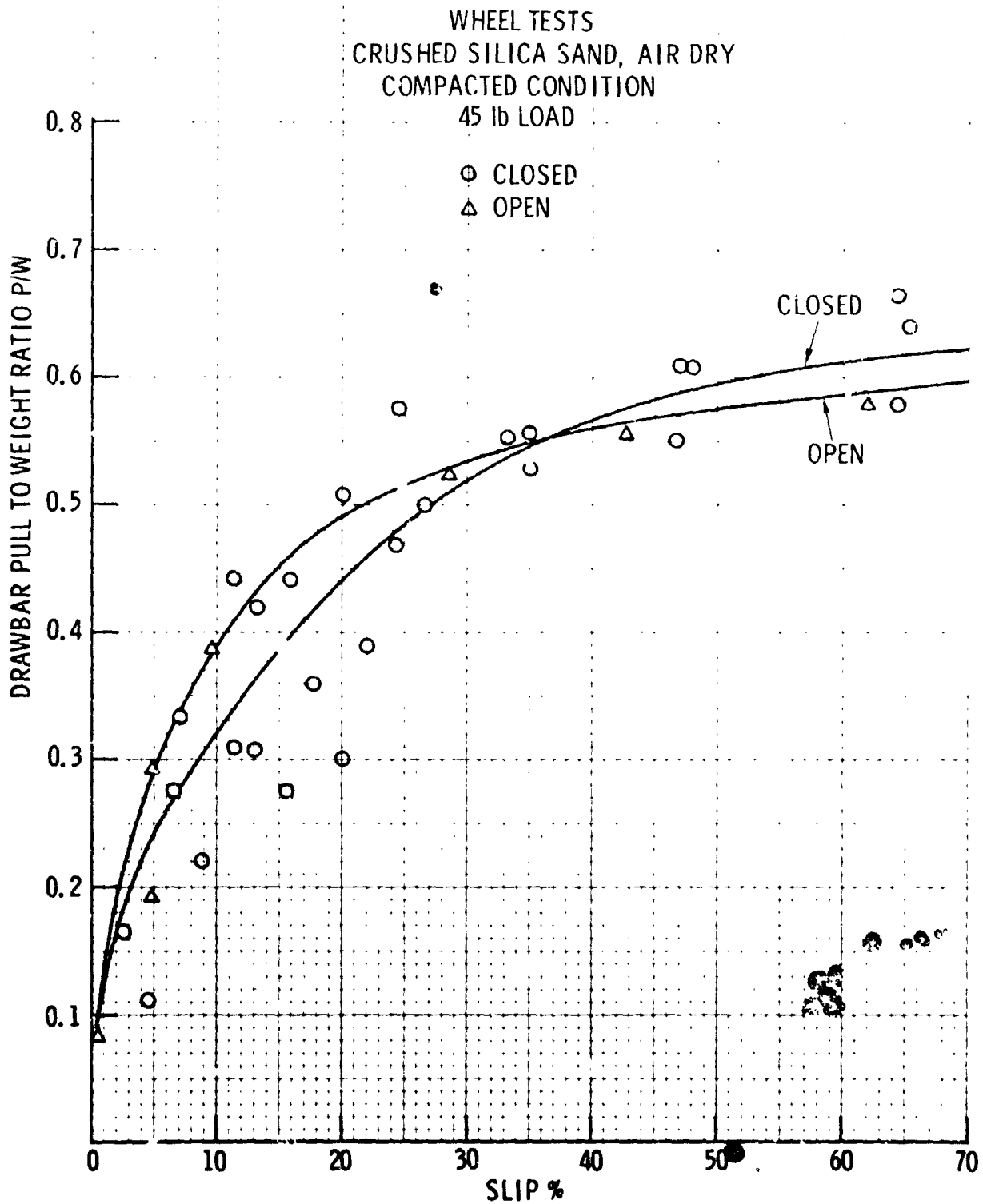


Figure 22 P/W vs Slip, 45 lb Load Summary, Compacted Soil Condition

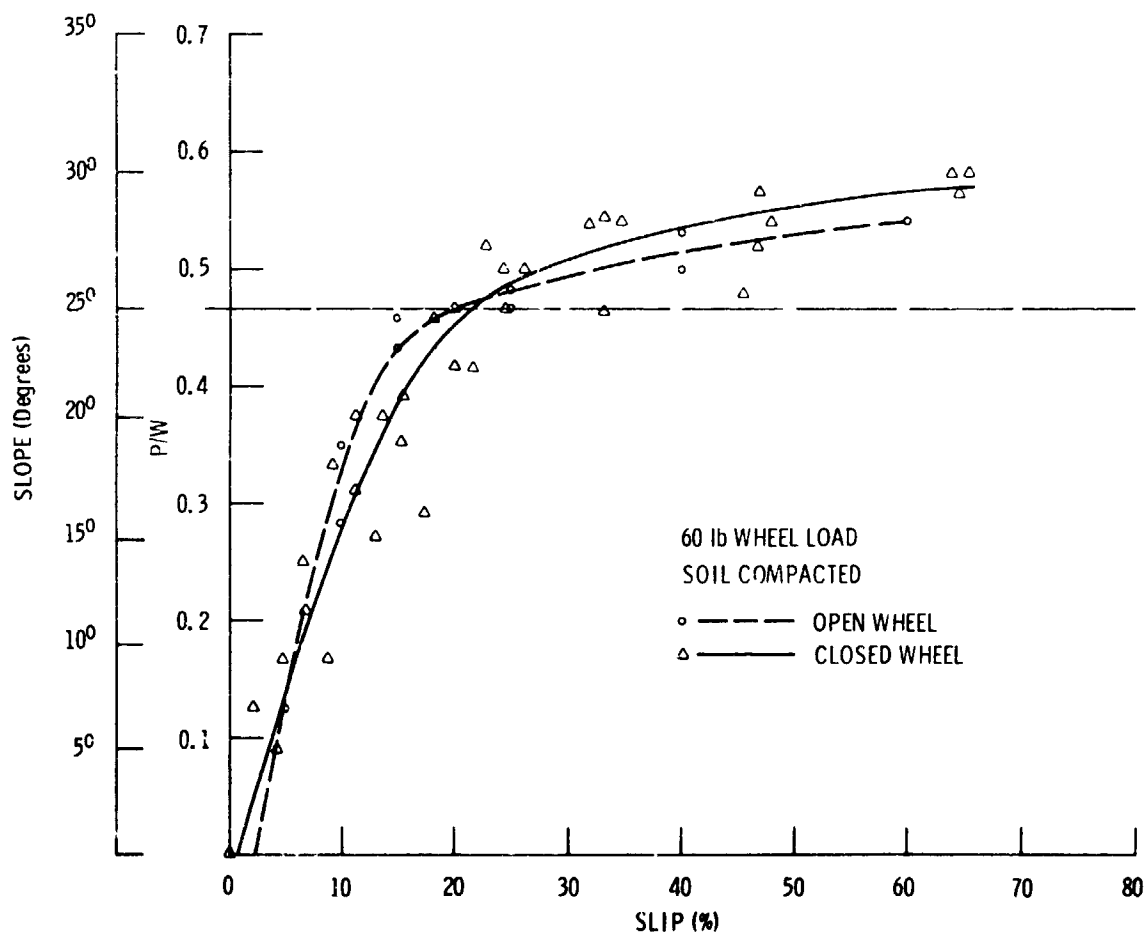
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Figure 23 P/W vs Slip, 60 lb Load Summary, Compacted Soil Condition

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Figure 24 Failure of Cover on One-Piece Fully Enclosed  
Pleated Fabric Design

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## 4.2 Mechanical Tests

4.2.1 Scope of Test. Load Deflection Tests were performed on all breadboard wheels. These tests determined the spring rate characteristics of the breadboard wheels in three primary axes. During the tests, deflection and footprint data were recorded for loads of 30 lb, 45 lb, and 60 lb. These tests were repeated after soft soil tests for the wheels that were run in the soft soil.

Abstract – The load deflection tests showed that the actual deflection slightly deviated from the design deflection. The design equations were modified to get a better approximation. The deflection was not linear due to the continual addition of new wires to support the load as the load is applied. Also in the fabric covered wheels the fabric adds to the stiffness of the wheel.

When the wheels were retested after the soft soil tests, a significantly stiffer spring rate was found to exist for the covered wheel but not for the open wheel. It was determined that this was due to "ruffing" of the fabric surface by the sand, thereby increasing the coefficient of friction between the fabric and the wires.

## 4.2.2 Administrative Data

Test Condition – The tests were run at the AC-DRL test facility by the facility personnel.

### Test Dates:

<u>Date</u>	<u>Test</u>
12-11-69 to 12-12-69	3 Axis load deflection test on closed pleated wheel.
12-15-69	3 Axis load deflection test on open wheel.
1-16-70	Vertical load deflection curve on closed pleated wheel.
1-16-70 to 1-19-70	Vertical load deflection curve on closed woven wheel.
1-22-70	Vertical load deflection curve on semiclosed wheel.
2-6-70	Vertical load deflection curve on open wheel.

Test Samples – All the tests were run on breadboard wheels. These are described in paragraphs 2.1 and 2.2.



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Test Facilities – The equipment required to perform the tests specified herein is listed in Table V and described below.

Table V  
TEST EQUIPMENT

Test	Test Equipment
Load-Deflection	(1) 3-Axis Load-Deflection Test Apparatus (2) Linear Potentiometer (3) Bridge Balance Box (4) 3-Axis Table (5) Wheel Support Fixture

Wheel Deflection and Associated Equipment – The deflection apparatus consists of six-load cells mounted between two parallel plates. Three load cells are located at the corners of an isosceles triangle for measuring vertical load. Two load cells measure the lateral wheel loads. A single load cell is used to determine the tangential load. The upper plate is covered with heavy emery cloth to provide a high friction surface (see Figure 25).

The wheel spring rate test setup uses a milling machine to provide the test loads and travel. The wheel is fastened rigidly to the locked arbor by means of a special adapter. The apparatus in turn is fastened to the machine feed table which allows motion in any of the three principal axes. The milling machine applies a load to the wheel and, in conjunction with a deflection potentiometer, provides a readout to any x-y plotter which gives the plot directly.

A linear potentiometer provides a readout of the table movement from a fixed reference point.

Test Requirements – The tests were run in accordance with the following procedure:

Set-Up – The wheel shall be mounted rigidly to the wheel support structure which in turn shall be attached to the overarm supports of a horizontal milling machine. The deflection-apparatus shall be placed on the table of the milling machine and appropriate connections shall be made to the bridge balance box and the x-y plotter. The linear potentiometer shall be located to record the wheel deflection in either the vertical, lateral, or longitudinal direction.

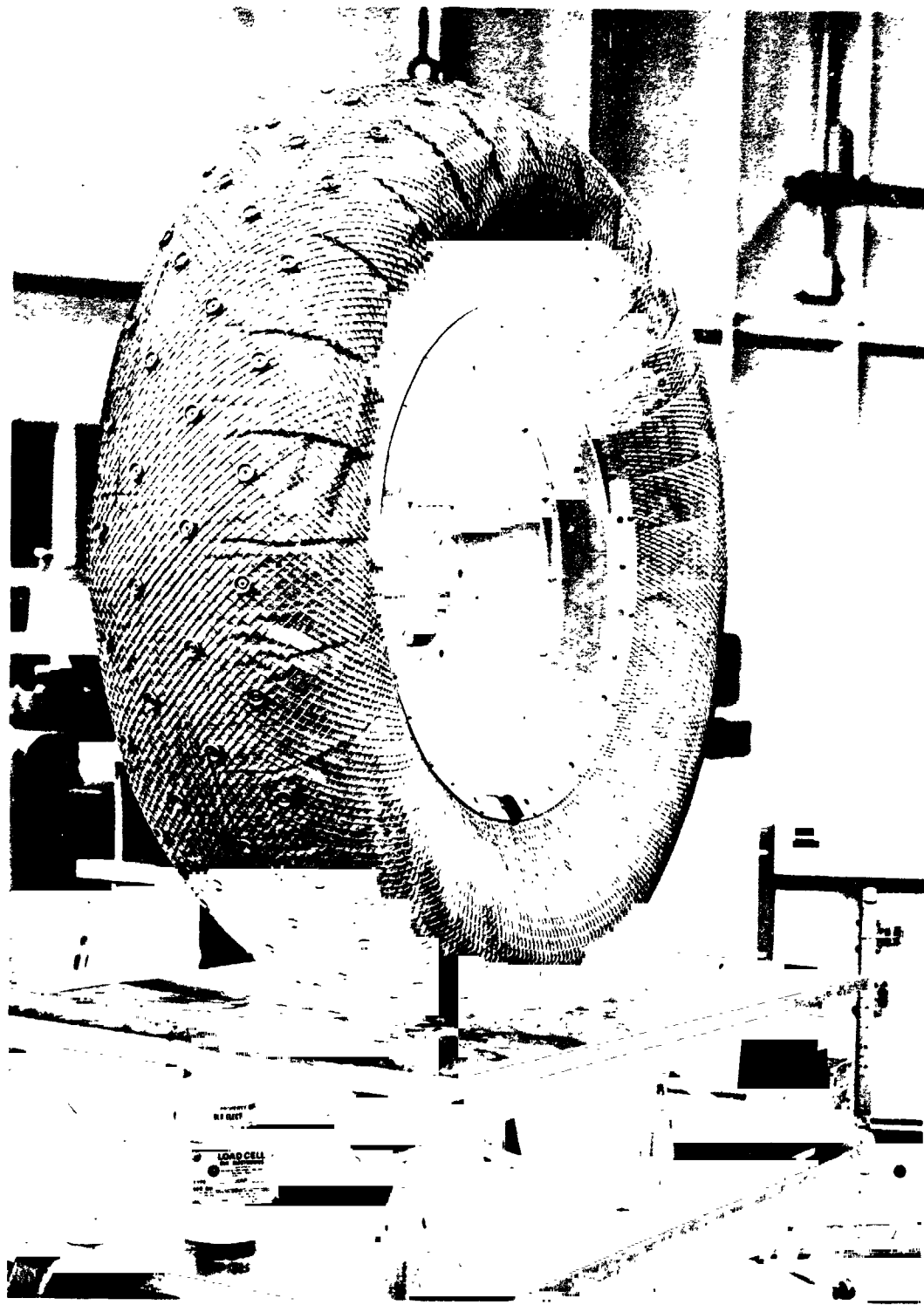


Figure 25 Load Deflection Tests

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Vertical Load -- Deflection -- The wheel shall be deflected from 0 to 4 inches and the load-deflection curve shall be recorded.

The contact length and width shall be measured and recorded at 30, 45, 60 lbf and at maximum deflection.

Lateral Load -- Deflection -- A vertical load of 60 lbf shall be applied to the wheel. The wheel shall then be deflected laterally until the wheel slippage occurs at the function surface. The lateral load-deflection curve shall be recorded.

Tangential Load -- Deflection -- A vertical load of 60 lbf shall be applied to the dynamometer surface. The wheel shall then be deflected tangentially until slippage occurs at the function surface. The longitudinal load-deflection curve shall be recorded.

Disposition of Test Samples -- The test samples were sent to the next test in the test sequence after the load deflection tests.

**4.2.3 Chronological Report of Test.** Mechanical test was performed on closed pleated wheel. The vertical load vs deflection curve was measured at four positions (90 degrees apart) with a 1/16-inch rubber base. The measurements were repeated 3 times at each location. Figure 26 shows the results of these measurements. The lateral load vs deflection was measured twice at the same location with a 60 lb vertical load and for the following bases: 1/16" rubber, plastic strip, and plywood with holes. Figures 27 through 29 show the results of these measurements. The tangential load vs deflection curve was measured twice at three locations (90 degrees apart) with a vertical load of 60 lb and on a plywood base with holes. Figure 30 shows the results of the measurements. Wire profiles were recorded at two wheel positions for the following conditions: no load, 1 inch deflection, 2 inch deflection, and 3 inch deflection (see Figure 31). The wheel footprint was recorded at four different wheel positions (90 degrees apart) for vertical wheel loads of 30, 45, and 60 lb (see Figure 32).

**Mechanical test of open wheel.** -- The vertical load vs deflection curve was measured at 4 positions (90 degrees apart) with a 1/16" rubber base. Figure 33 shows the results of these measurements. Lateral load vs deflection curve was measured with a 60 lb vertical load and at the same location for the following bases: 1/2" felt, and double back tape. Figures 34 and 35 show the results of these measurements.

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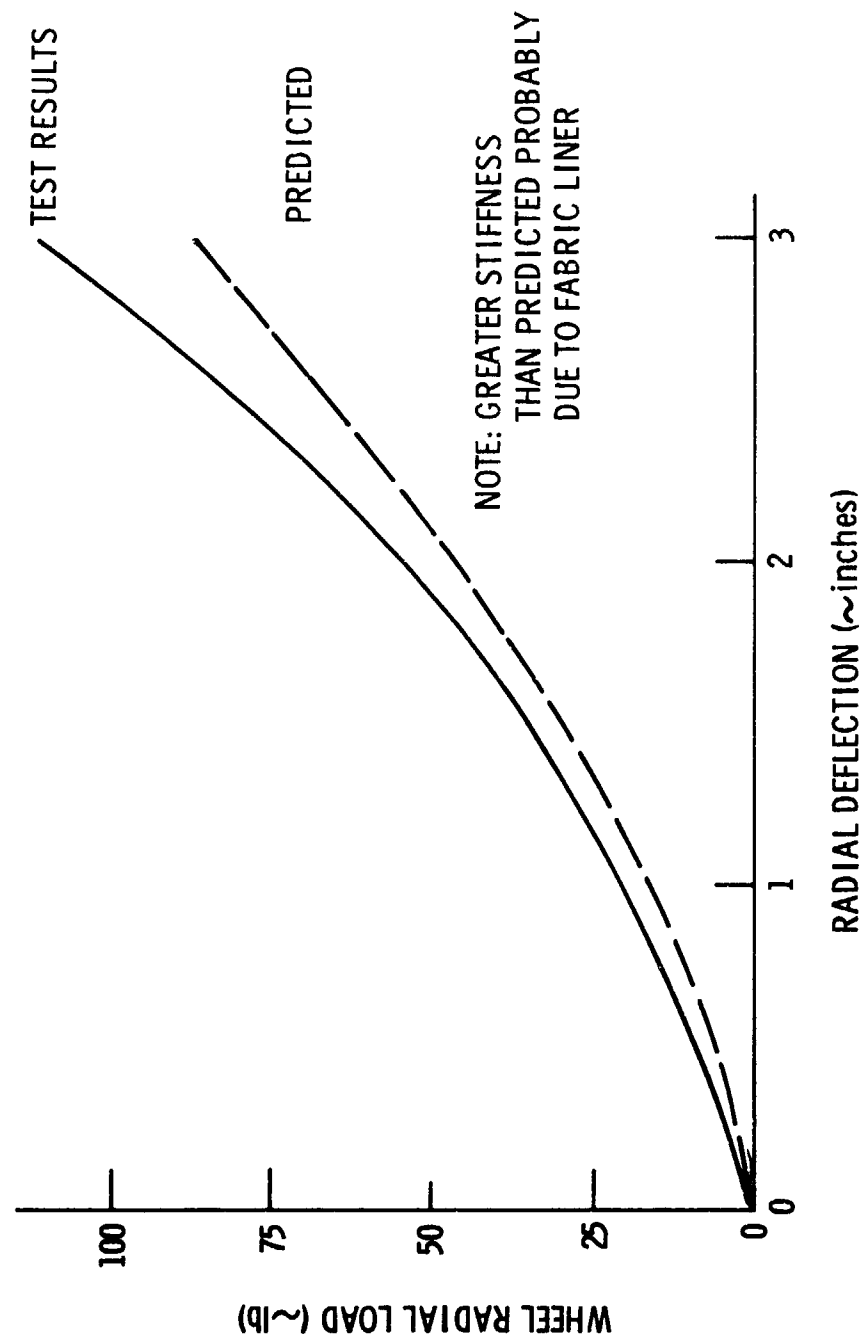


Figure 26 Radial Deflection - Breadboard Wheel Load vs Deflection: Double Mesh, Closed Pleated Armalon Liner, 0.027 in. Dia. Wire (12/11/69)

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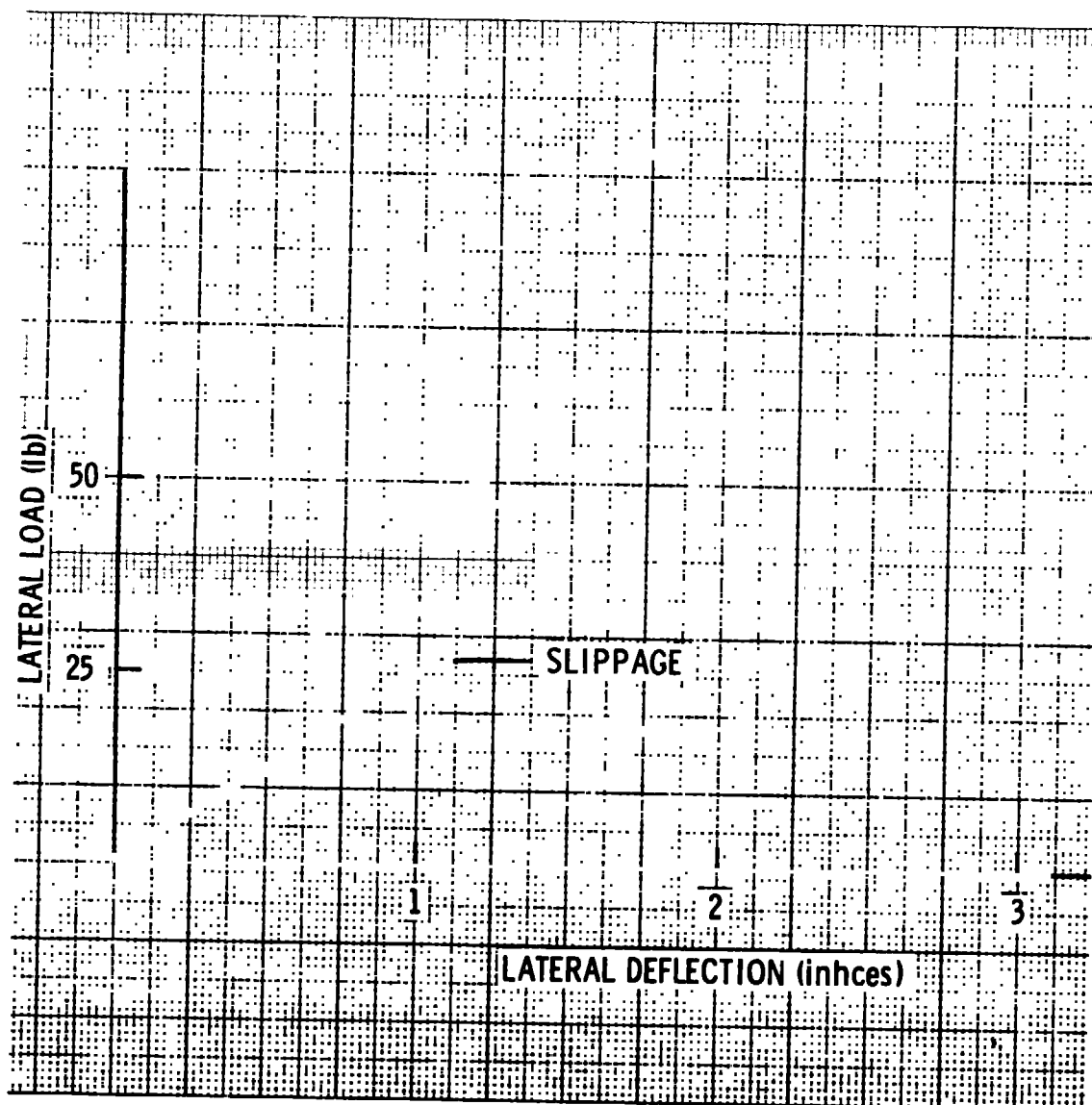


Figure 27 Lateral Deflection (inches) - Breadboard Wheel Lateral Load vs Deflection; 1/16 in. Rubber Base, Closed Pleated Armalon Liner, 0.27 in. Dia. Wire (12/11/69); 60 lb Vertical Load

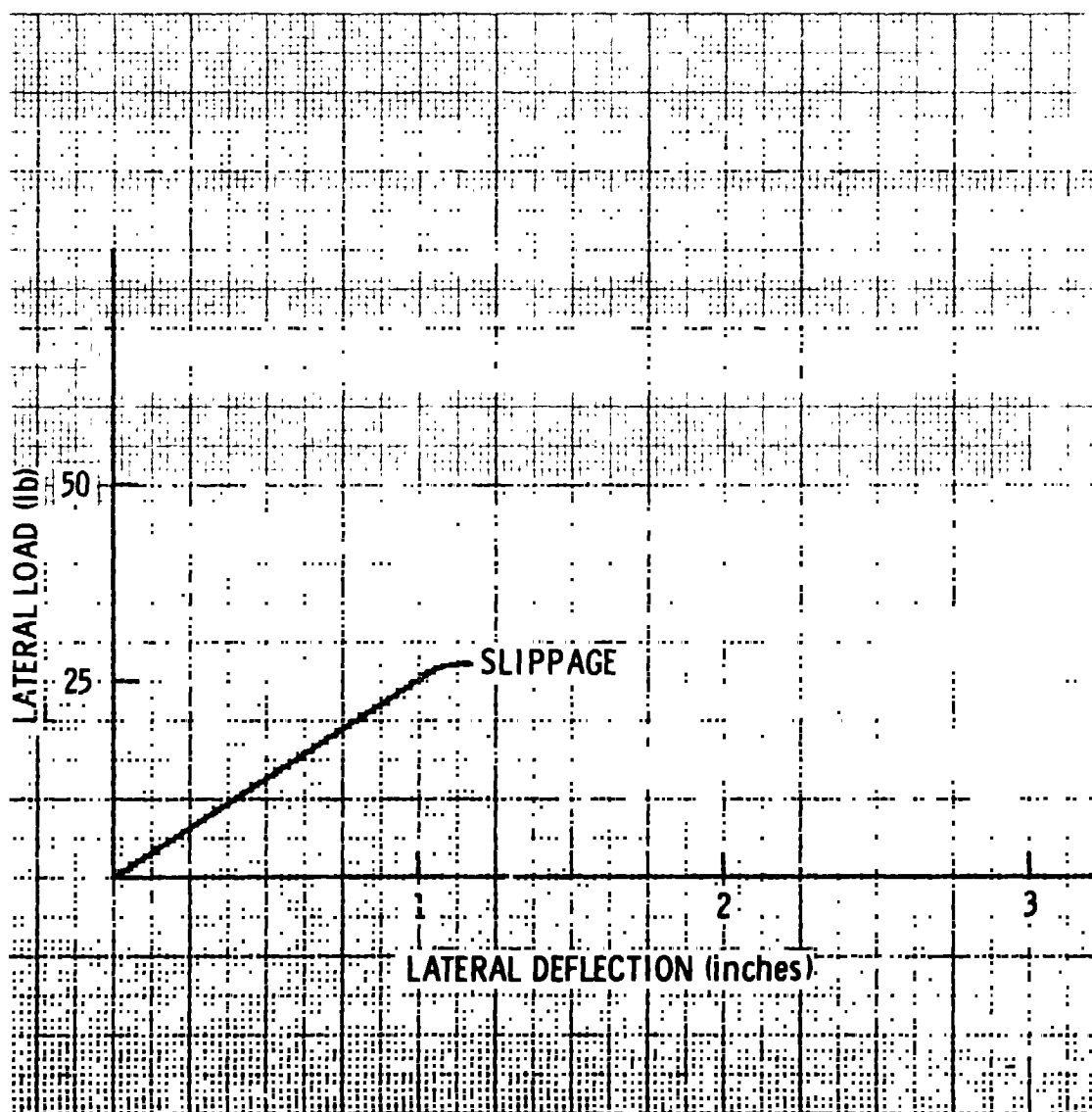
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Figure 28 Lateral Deflection (inches) -- Breadboard Wheel Lateral Load vs Deflection; Plastic Strip Base, Closed Pleated Armalon Liner, 0.27 in. Dia. Wire (12/12/69); 60 lb Vertical Load

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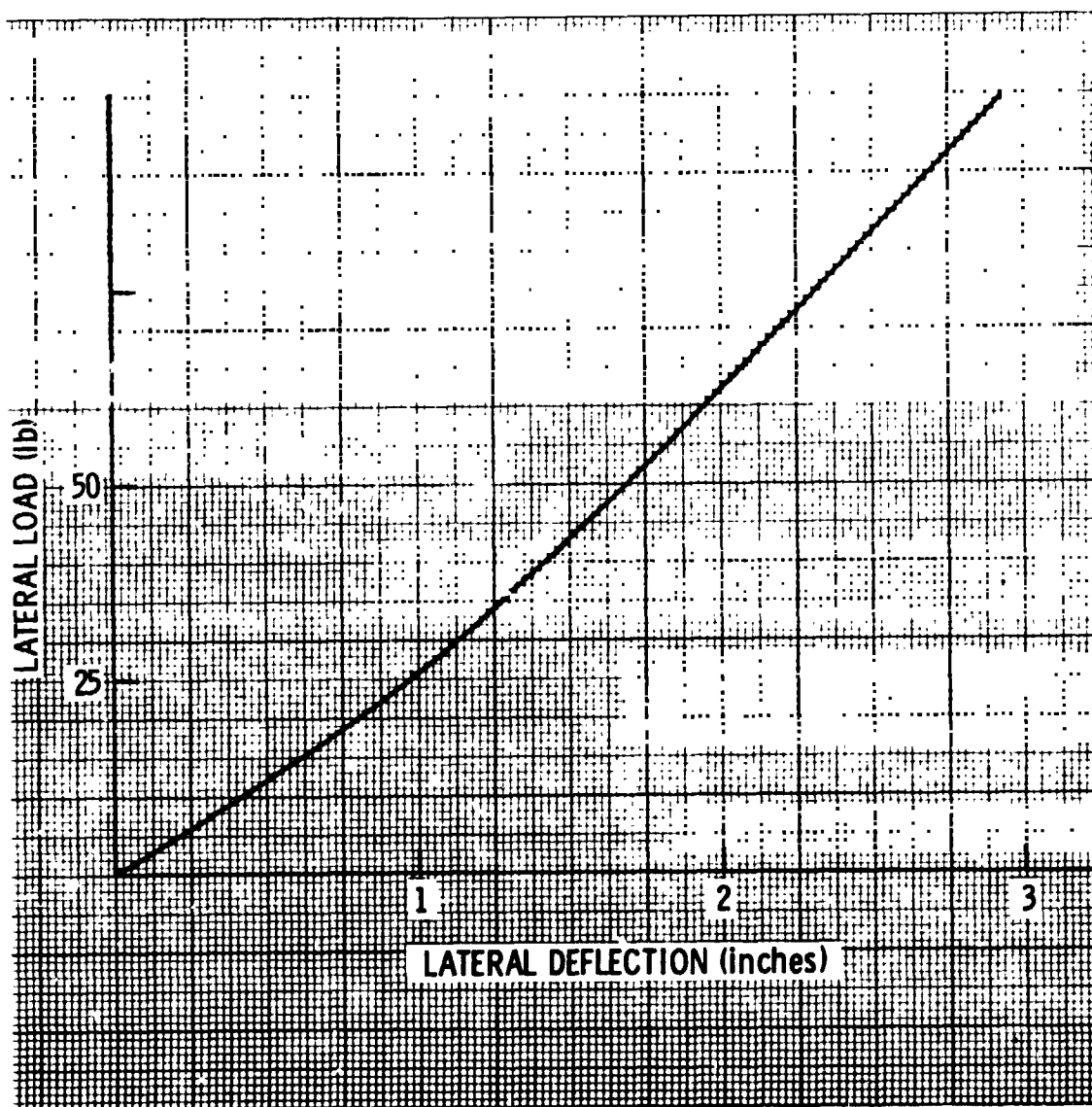


Figure 29 Lateral Deflection (inches) – Breadboard Wheel Lateral Load vs Deflection; Base: Plywood with holes; Closed Pleated Armalon Liner, 0.27 in. Dia. Wire (12/12/69); 60 lb Vertical Wheel Load

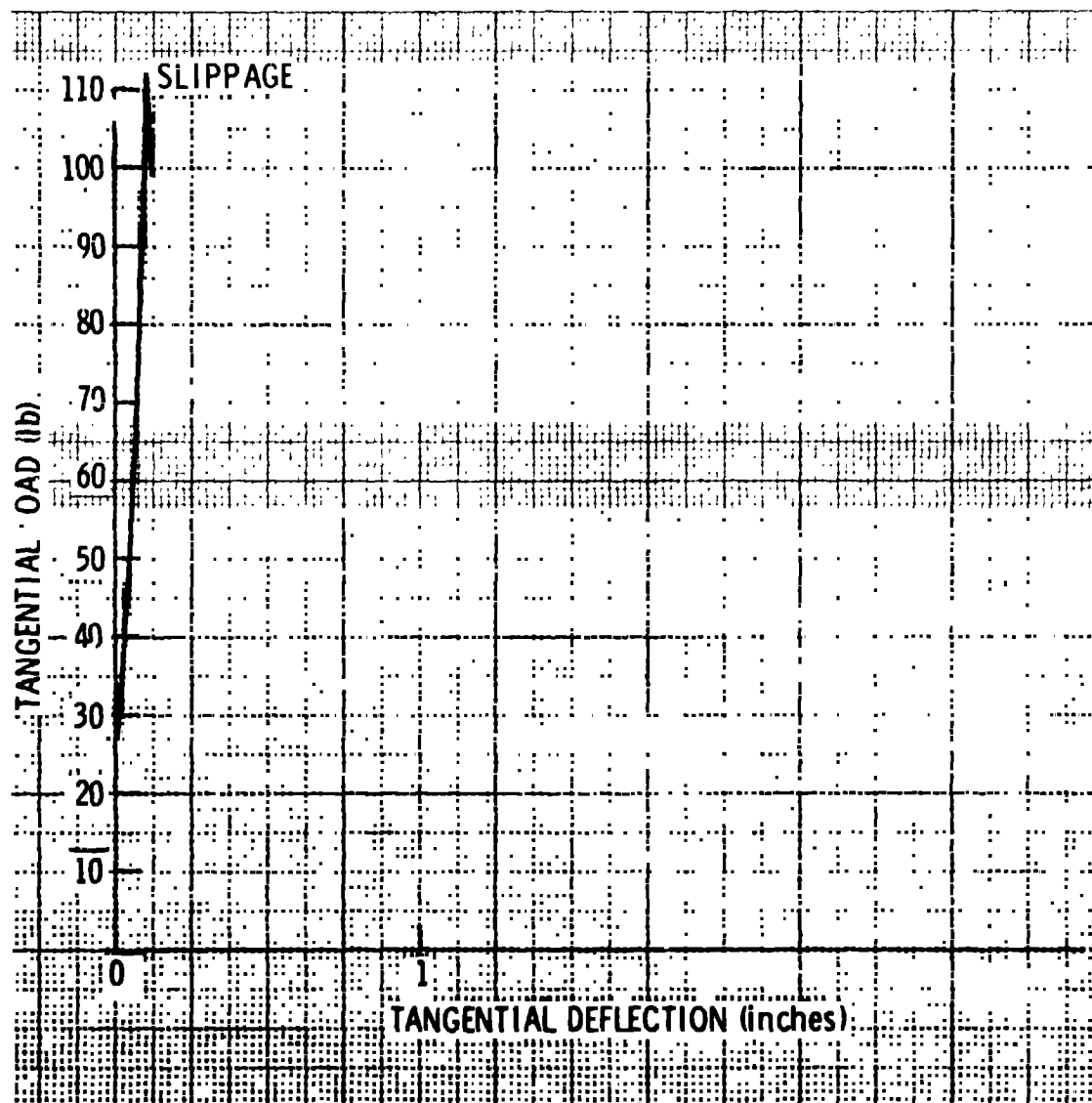
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Figure 30 Tangential Deflection (inches) - Breadboard Wheel Tangential Load vs Deflection; Base: Plywood with Holes; Closed Pleated Armalon Liner, 0.27 in. Dia. Wire (12/12/69); 60 lb Vertical Wheel Load



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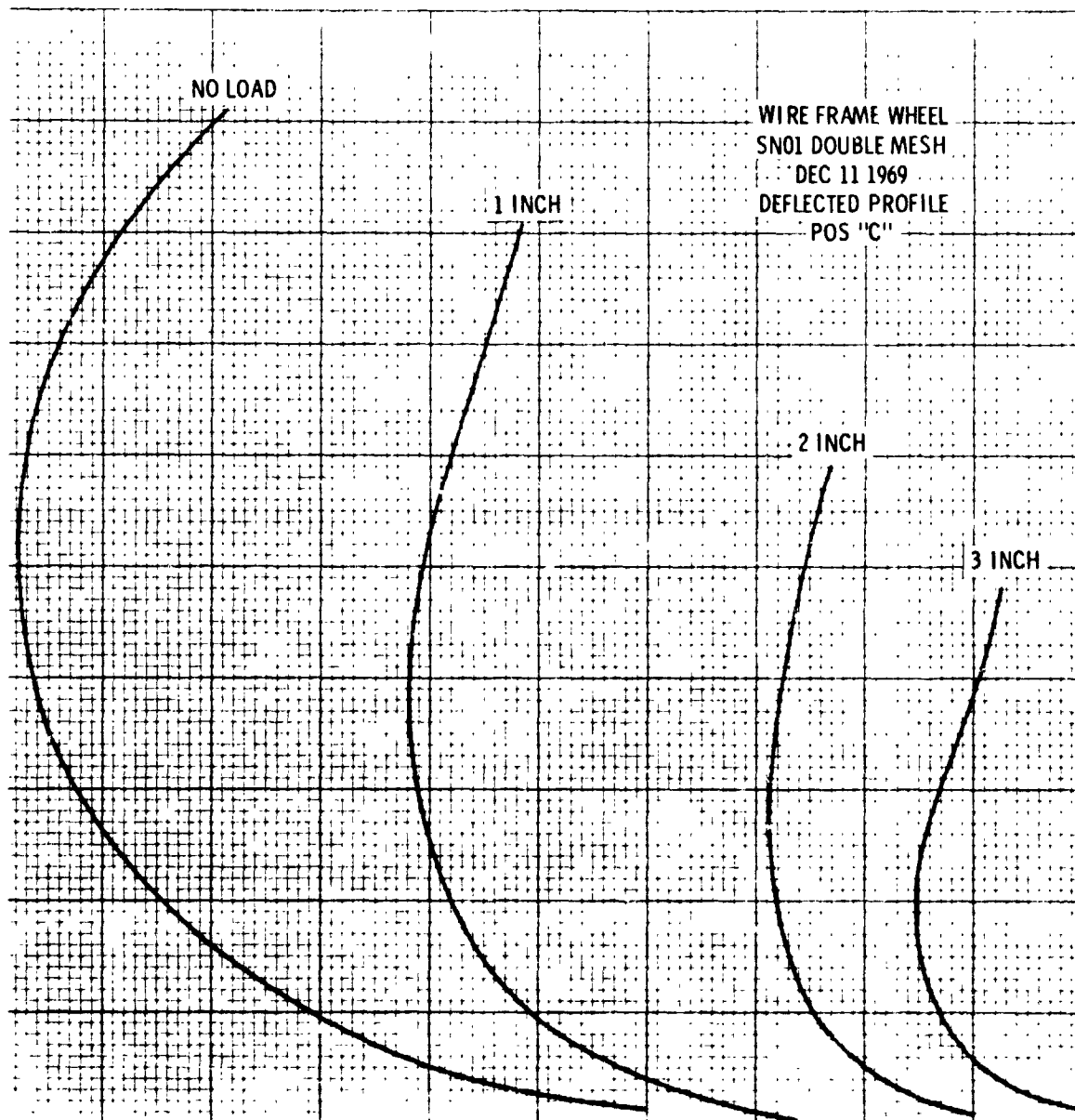


Figure 31 Deflected Profile, Position "C" – Wire Frame Wheel, SN01  
Double Mesh (12/11/69)

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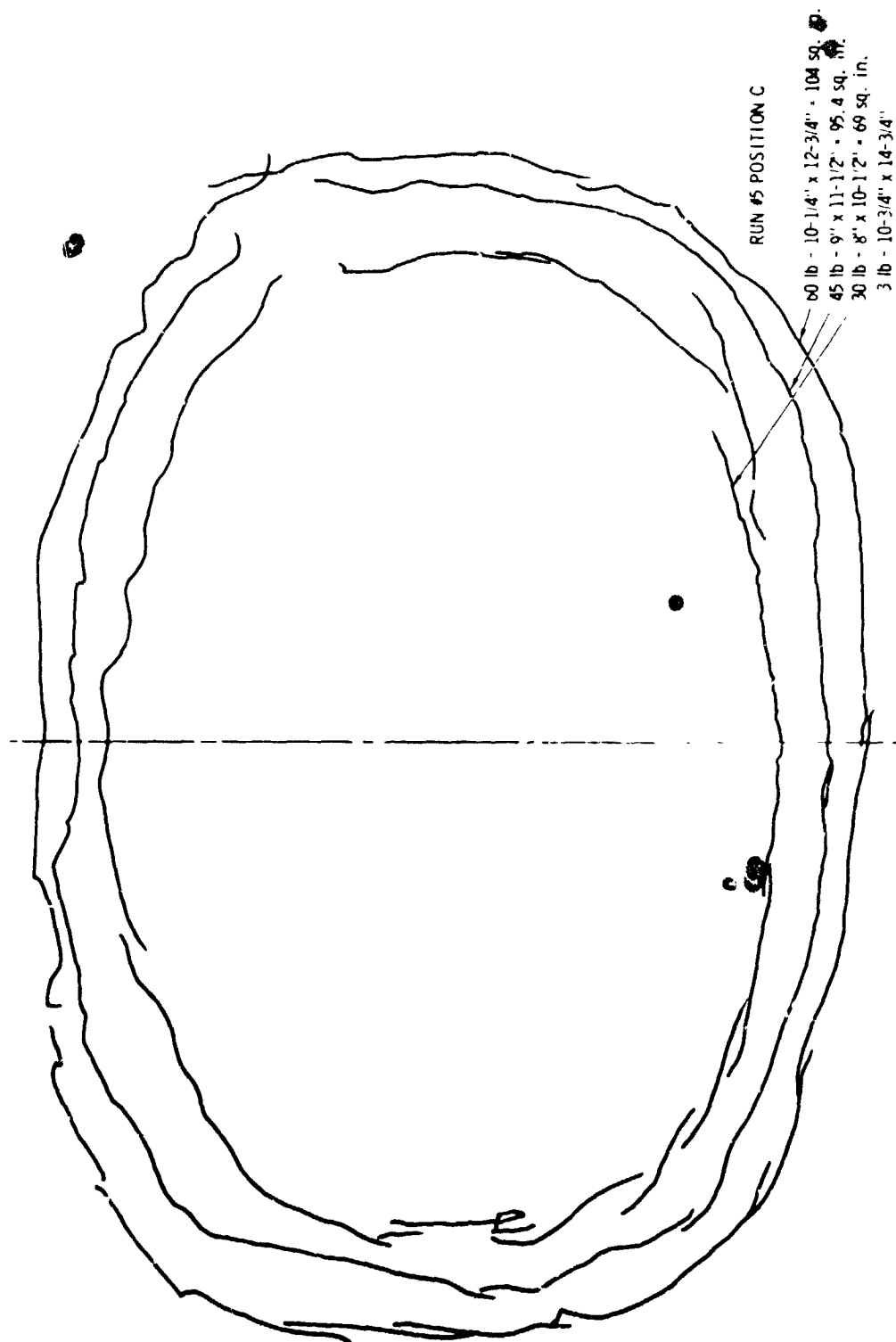


Figure 32 Wheel Footprint - Run No. 5, Position "C"

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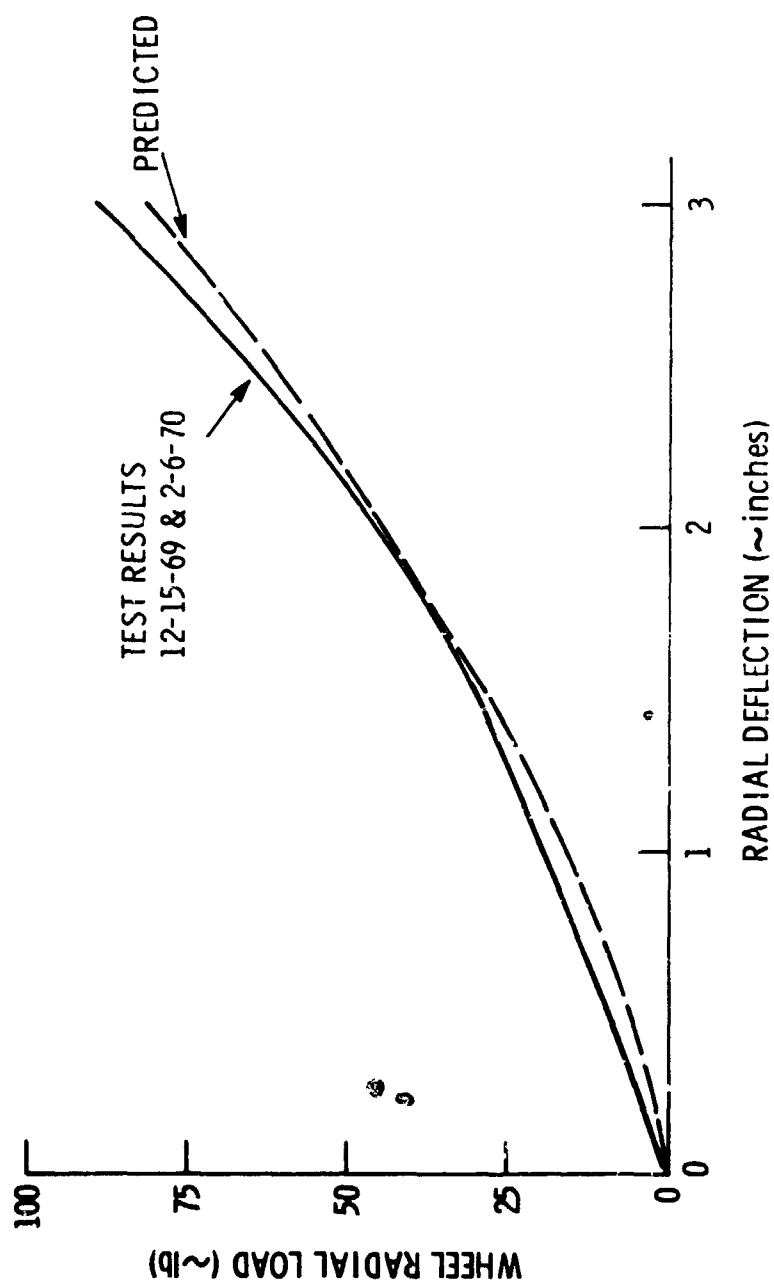


Figure 33 Radial Deflection - Breadboard Wheel Load vs Deflection: Single Open Mesh, 0.032 in. Dia. Wire

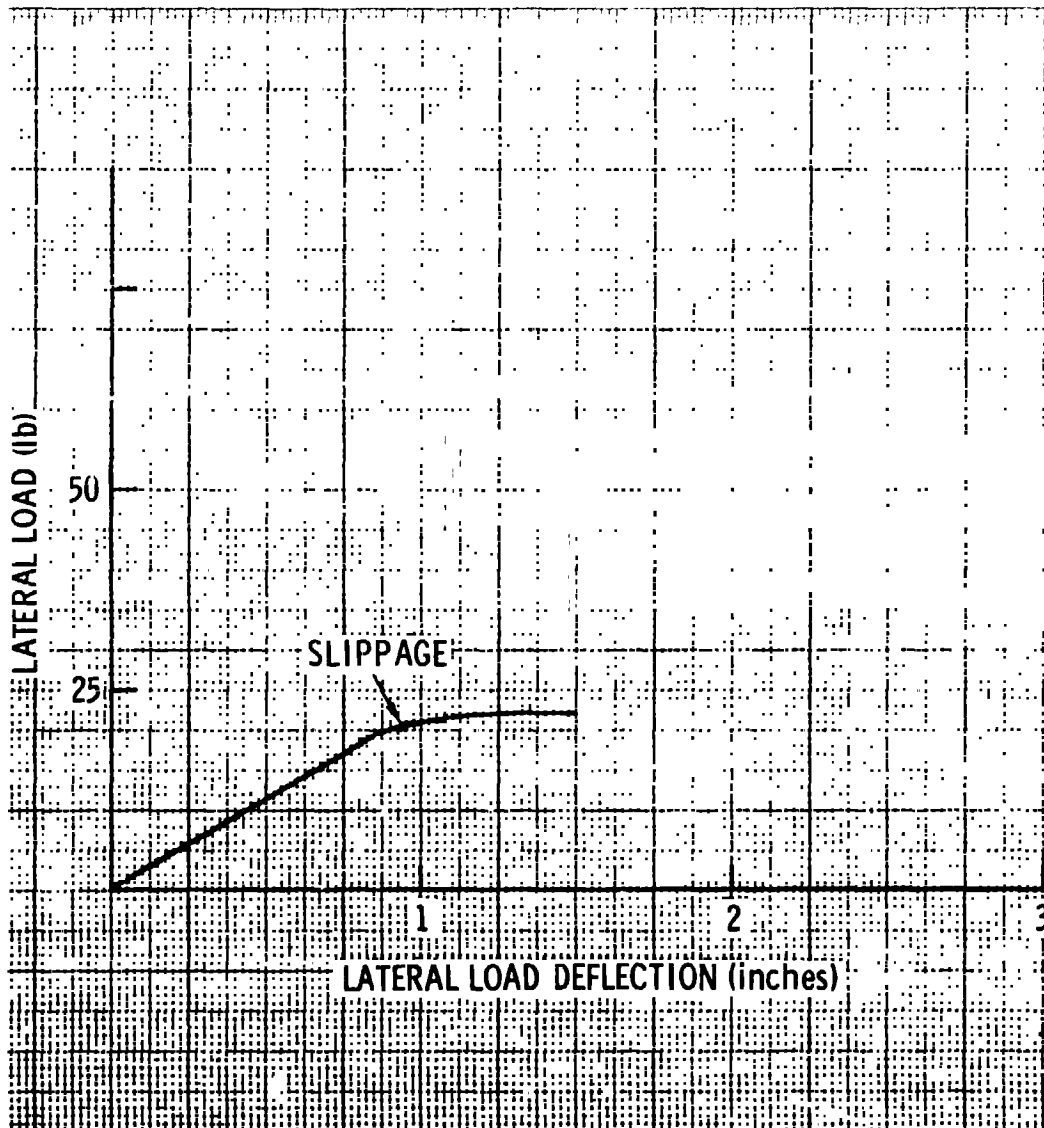
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Figure 34 Lateral Deflection (inches) – Breadboard Wheel! Lateral Load vs Deflection; 1/2 in. Felt Base; Single Open Mesh, 0.32 in. Dia. Wire (12/15/69); 60 lb Vertical Wheel Load

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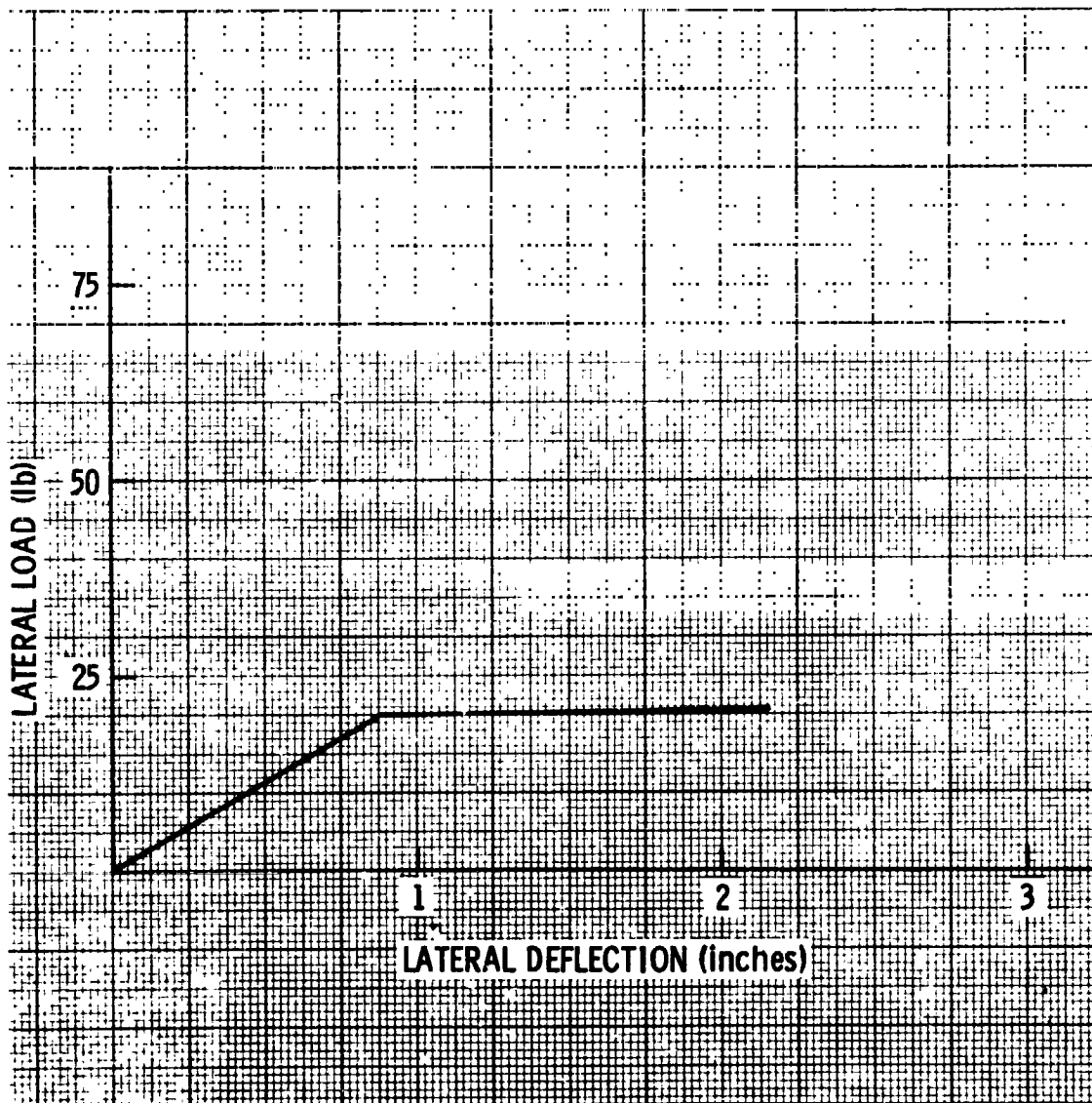


Figure 35 Lateral Deflection (inches) – Breadboard Wheel Lateral Load vs Deflection; Double-Back Tape Base; Single Open Mesh, 0.32 in. Dia. Wire (12/15/69); 60 lb Vertical Wheel Load

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Wire profiles were recorded at two wheel positions for the following conditions: no load, 1 inch deflection, 2 inch deflection, and 3 inch deflection (see Figure 36). The wheel footprint was recorded at four different wheel positions (90 degrees apart) for wheel loads of 30, 45, and 60 lb (see Figure 37).

Vertical load vs deflection curve was measured on the closed pleated wheels. The measurement was repeated twice with a 1/16" rubber base for the following conditions: dry bases, sprayed with WD-40 and run on rolling road for 5 minutes. Figure 38 shows the results of these measurements.

Vertical load vs deflection curve was measured on the closed woven wheel after the completion of a 1,000 cycle smooth load conditioning. The measurement was repeated 3 times at two different locations (90 degrees apart). Figure 39 shows the results of the measurements.

Vertical load vs deflection curve was measured on the semi-closed wheel after the completion of a 1,000 cycle smooth road conditioning. The measurements were done using the Tinius Olsen. The test setup is shown in Figure 40. The measurement was performed at three different wheel locations (90 degrees apart). Figure 41 shows the results of the test.

Vertical load vs deflection curve was measured on the open wheel after the completion of the soil test. The measurement was repeated 3 times at 3 locations (90 degrees apart). Figure 33 shows the results of the measurement.

#### 4.3 Wheel Endurance Test

##### 4.3.1 Scope. The tests were performed

- a. To determine the ability of each wheel to withstand dynamic loads generated when encountering obstacles.
- b. To find the endurance limit of the wheels over a smooth surface and an obstacle course.

**Abstract** – Endurance tests were performed on the three covered-wheel types as well as the open-wheel configuration as described in paragraphs 2.1 and 2.2. The closed pleated wheel contained a split in the Armalon fabric which occurred during the soil test. This split increased to the point where it was necessary to halt the test after 6,353 revolutions.

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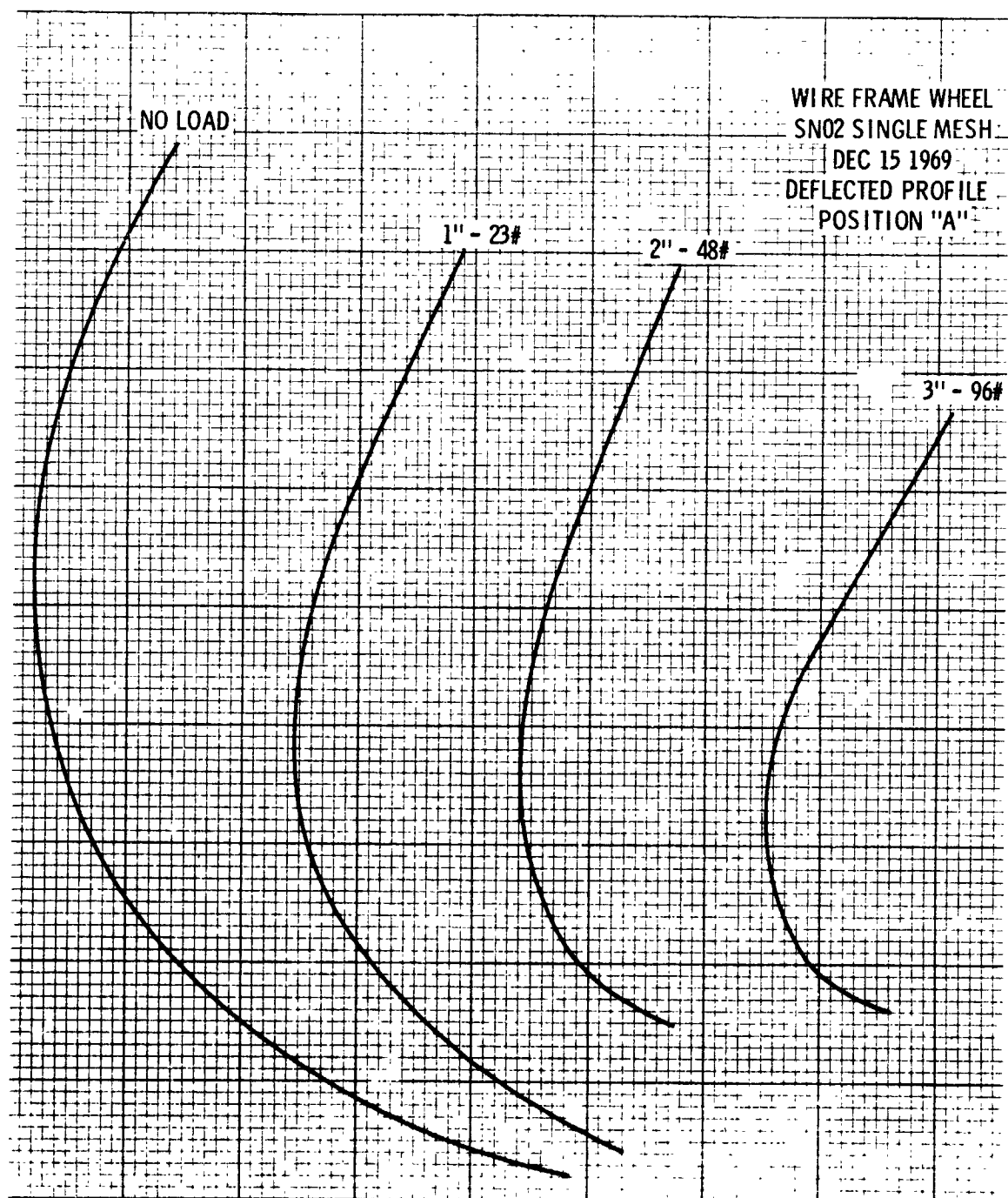


Figure 36 Deflection Profile, Position "A" - Wire Frame Wheel, SN02  
Single Mesh (12/15/69)

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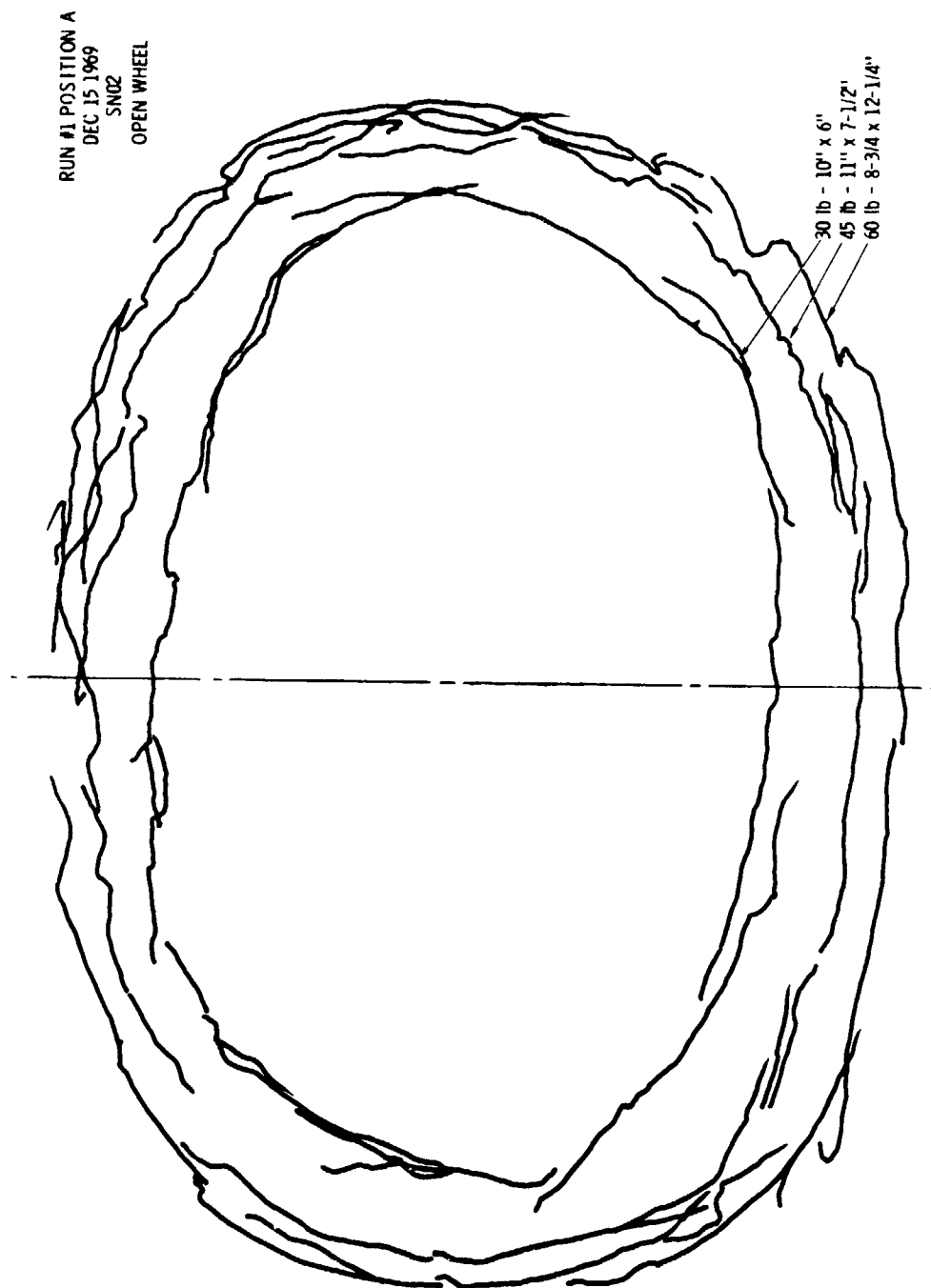


Figure 37 Wheel Footprint -- Run No. 1, Position "A",  
SN02 Open Wheel (12/15/69)



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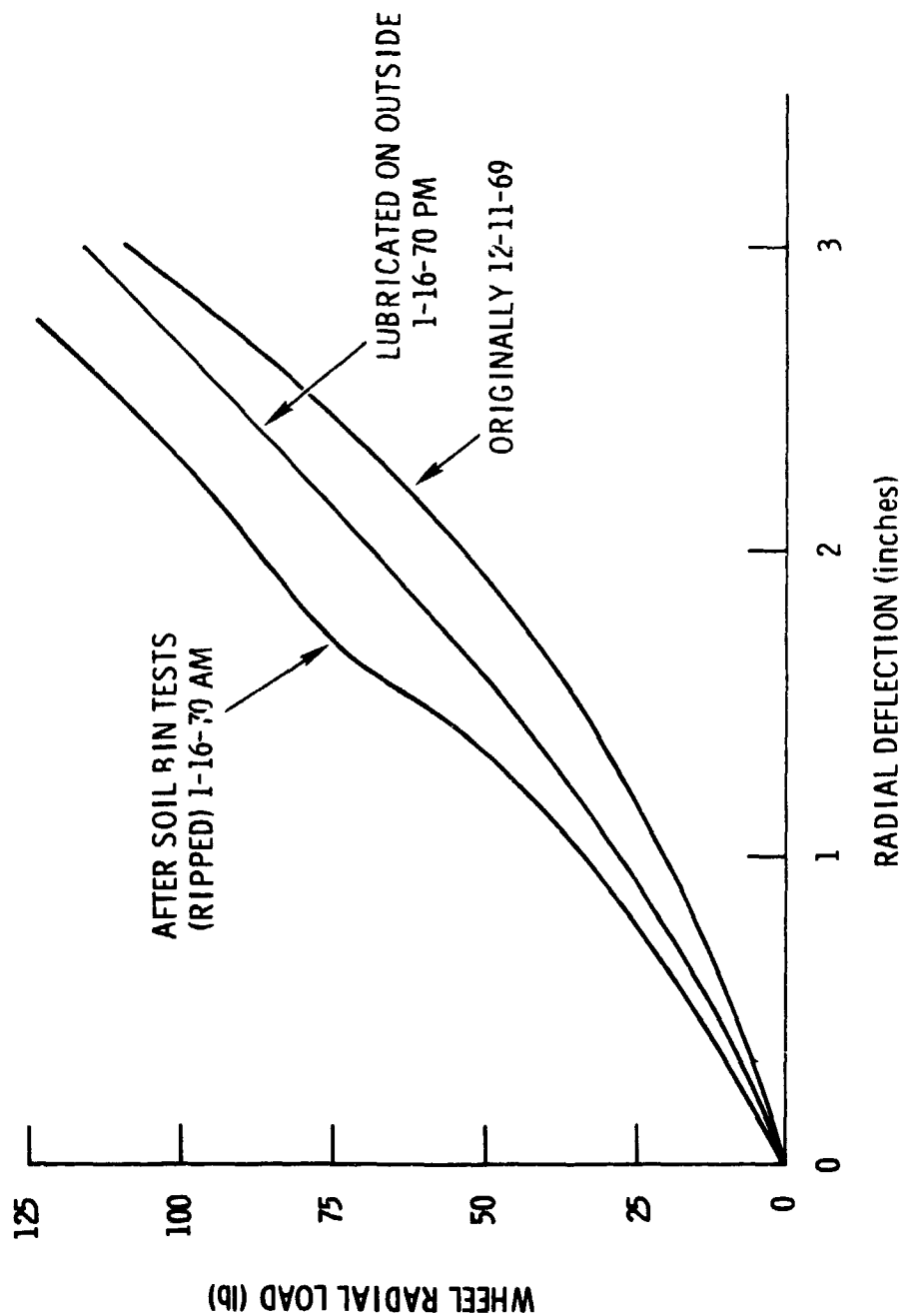


Figure 38 Radial Deflection (inches) - Wheel Load vs Deflection: Double Mesh, Closed Pleated Armalon with 0.027 in. Wire Dia.

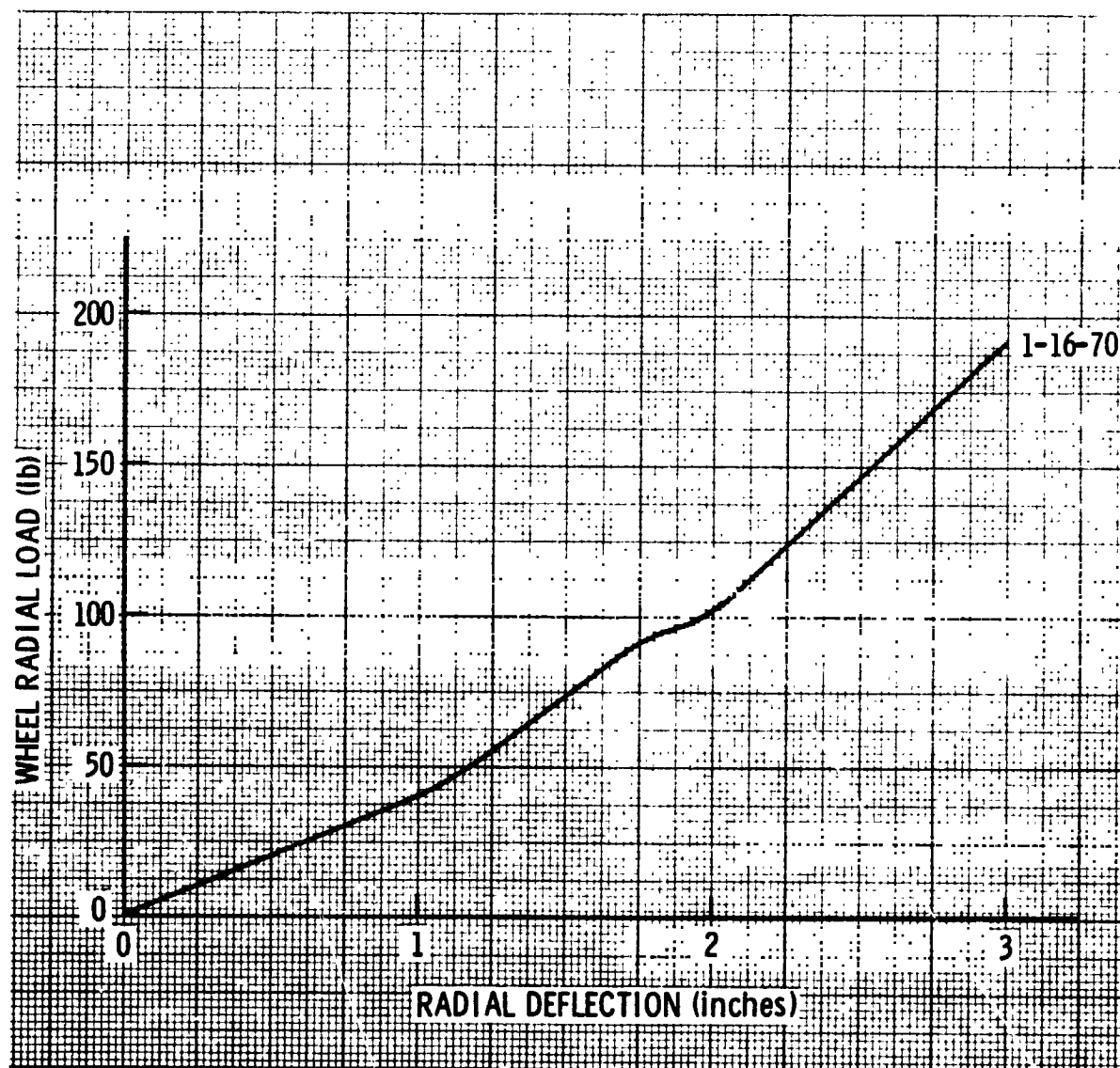
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Figure 39 Radial Deflection (inches) – Breadboard Wheel vs Deflection,  
0.027 in. Dia. and 0.032 in. Dia. Double Mesh, Woven  
Armalon Liner

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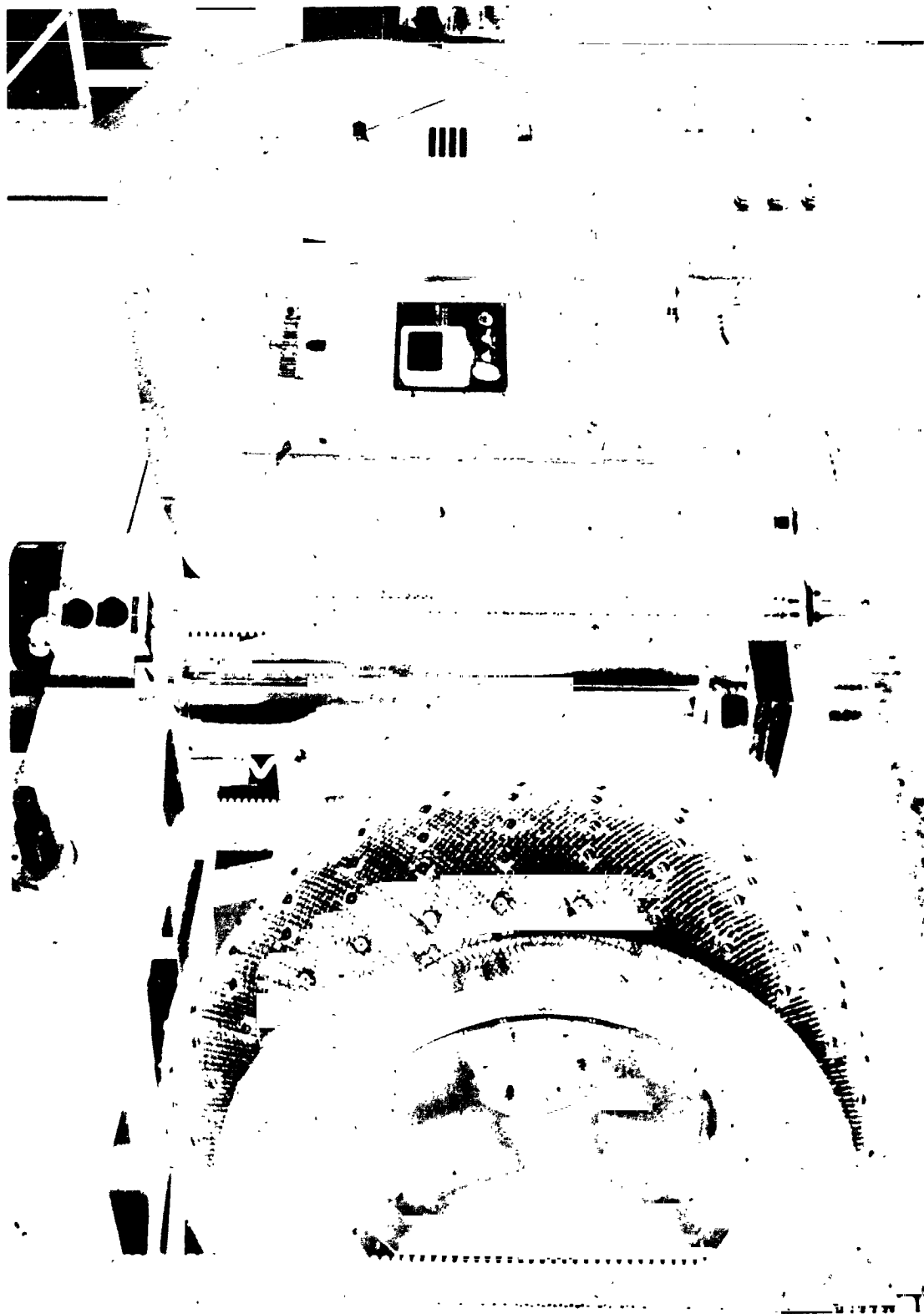


Figure 40 Deflection Test on Timius-Olsen Equipment

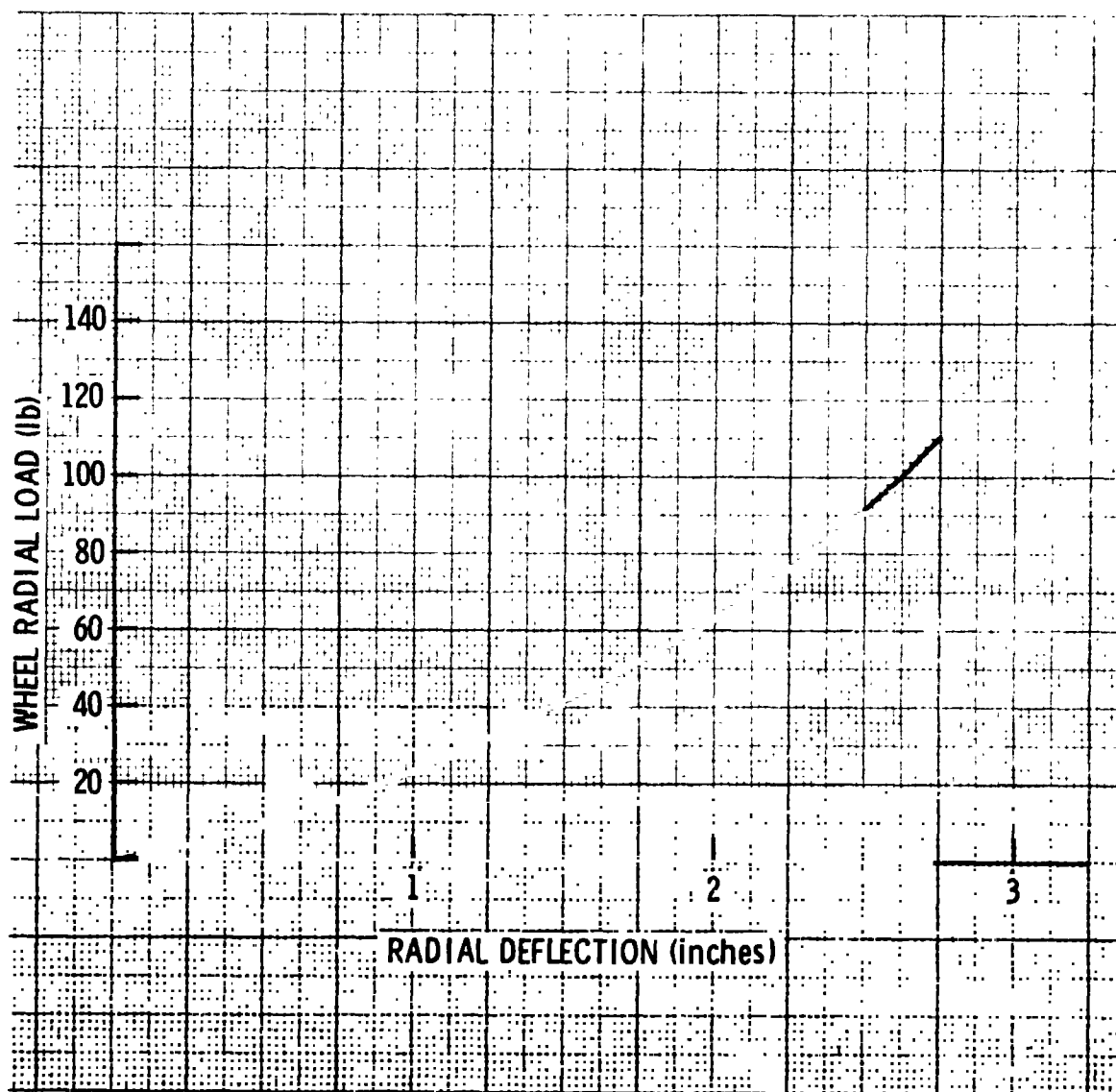
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Figure 41 Radial Deflection (inches) – Breadboard Wheel Load vs Deflection  
0.027 in. Dia. Double Wire Mesh Diagonal Overlap Armalon  
Fabric (1/22/70)

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The closed woven wheel was successfully subjected to 50,000 revolutions or 117 km of smooth road testing. The obstacle test was halted after 33 revolutions during the instrumentation checkout due to the mesh separating from the rim. This was attributed to the absence of RTV normally put in the mesh under the rim. The wheel was repaired and subjected to 25,000 revolutions or 58 km on the obstacle track. A slight amount of wire breakage was noted, especially in the button area.

The semi-enclosed wheel was also successfully subjected to 50,000 revolutions or 117 km of smooth road testing. The obstacle test was halted after 5,000 revolutions or 12 km due to excessive wire breakage adjacent to the buttons.

The open wheel was run a total of 75,079 revolutions on the smooth road. After the completion of this test the wheel was examined and a total of five broken wires were found.

#### 4.3.2 Administrative Data

The test was conducted at AC Electronics - Defense Research Laboratories, General Motors Corporation, in Santa Barbara, California, on the following dates:

<u>Dates</u>	<u>Test</u>
1-15-70	Smooth surface endurance test on the closed pleated wheel. The test was stopped after 6,353 cycles due to an enlarged split in the Armalon fabric.
1-15-70	1,000-revolution conditioning on the closed woven wheel.
1-17-70 to 1-19-70	50,000 cycles smooth surface endurance test on the closed woven wheel.
1-20-70	Obstacle endurance test on the closed woven wheel. The wheel failed after 33 cycles.
1-21-70	1,000-cycle conditioning on semi-enclosed wheel.
1-22-70	25,000 cycles obstacle endurance test on the closed woven wheel after repair.
1-23-70	50,000-cycle smooth surface endurance test on the semi-enclosed wheel.
1-23-70 to 1-24-70	Obstacle endurance test on the semi-enclosed wheel. The wheel failed after 5,000 cycles.
2-30-70 to 2-26-70	Smooth road endurance tests on open wheel design. Five broken wires were noted after 75,079 cycles.

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Test Samples – The test samples are described in paragraphs 2.1 and 2.2.

Test Facilities –

- (1) Rolling Road Facility
- (2) Wheel Support Structure
- (3) Instrumentation
  - (a) Accelerometers
  - (b) Wheel Revolution Counter
  - (c) Wheel Tachometer
  - (d) Belt Tachometer
  - (e) Wheel Torque Gages
- (4) Weights
- (5) Recorders
- (6) Test Obstacles
  - (a) 9.5 x 2 x 2 inch aluminum block
  - (b) 2 x 2 x 2 inch aluminum block
  - (c) 1 x 1 x 1 inch aluminum trapezoid
  - (d) 3 inch dia. aluminum half cylinder (1.5 inches thick)

Test Requirements – Since the purpose of these tests is the evaluation of the relative mechanical and dynamic performance of the two wheel concepts, there are no specific performance requirements to be met.

#### 4.3.3 Chronological Report of Test

Smooth surface endurance test was performed on closed pleated wheel. The test was conducted with a 60 lb wheel load and at a wheel speed of 80 rpm. There was a split in the Armalon fabric which occurred during the soil test (see Figure 24). This split increased to the point where it was necessary to halt the test after 6,353 cycles. The parts from this wheel were then used to construct semienclosed wheel.

Conditioning, consisting of 1,000 cycles on the smooth road, was performed on the closed woven wheel prior to load deflection test. The wheel was subjected to a 60 lb load and a wheel speed of 80 rpm during the conditioning.

Smooth surface endurance test consisting of 50,000 cycles was performed on the closed woven wheel. The wheel was subject to a 60 lb load and a wheel speed of 80

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rpm. The wheel was inspected and the deflection measured periodically. Figures 42 through 57 show the wheel condition at the various inspection points. The wheel deflection at 60 lb load increased at the end of the test by  $3/16''$  to the value of  $1-5/16''$ . There was a slight amount of fraying of the Armalon fabric at the wheel edges (see Figures 58 and 59). There were no apparent changes in wheel condition.

Obstacle endurance test was performed on the closed woven wheel. The wheel failed after 33 revolutions. The wire mesh parted from the rim (see Figures 58 and 59). The failure was due to the lack of RTV (GE silicone rubber bonding material) in bonding the wire mesh to the rim. The wheel was repaired with RTV.

The semi-enclosed wheel was subjected to 1,000 revolutions of conditioning on the smooth road. The wheel was subjected to a 60 lb load and a wheel speed of 80 rpm during break-in.

Obstacle endurance test consisting of 25,000 revolutions or 58 km was performed on the closed woven wheel. The wheel was subjected to a 60 lb load and a wheel speed in accordance with:

- a. 10,000 revolutions at 4 km/hr or 28.5 rpm.
- b. 15,000 revolutions at 8 km/hr or 57 rpm.

The wheel was inspected and the obstacles rearranged every 5,000 revolutions (see Figure 60). Wheel load was 60 lb. The torque, vertical acceleration, and wheel velocity were recorded. Figure 61 shows a typical recording. Figures 62 through 69 show the wheel conditions at various inspection points.

Smooth surface endurance test consisting of 50,000 cycles was performed on the semi-enclosed wheel. The wire and parts from the closed pleated wheel were used to produce the semi-enclosed wheel. Thus, the wire in the semi-enclosed wheel had 6,353 cycles on it prior to the start of the test resulting in a total test of 56,353 cycles on the smooth surface. The wheel during the test was subject to a 60 lb load and a wheel speed of 80 rpm. Figures 70 through 75 show the wheel condition at various inspection points in test.

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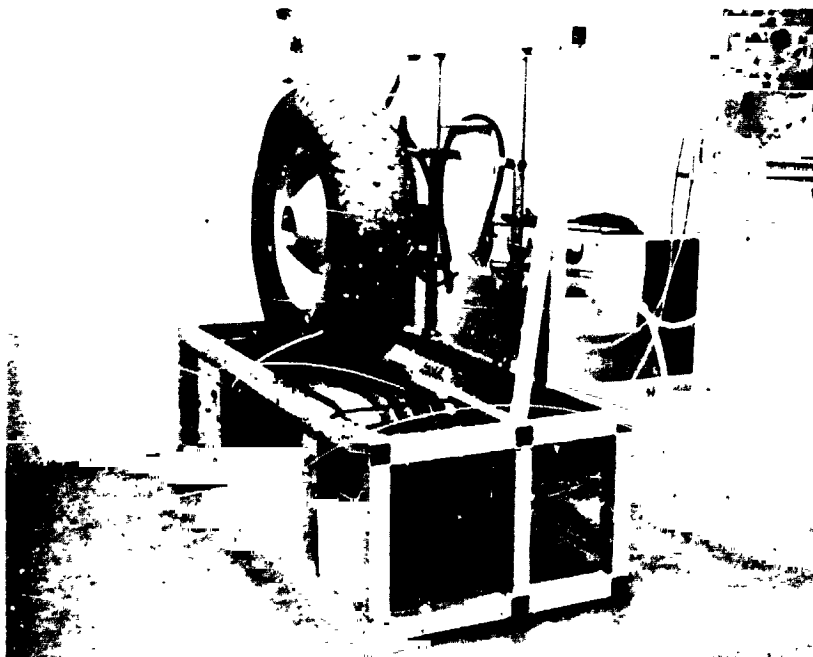


Figure 42 Setup for Smooth Surface Endurance and 1,000-Cycle Conditioning Test

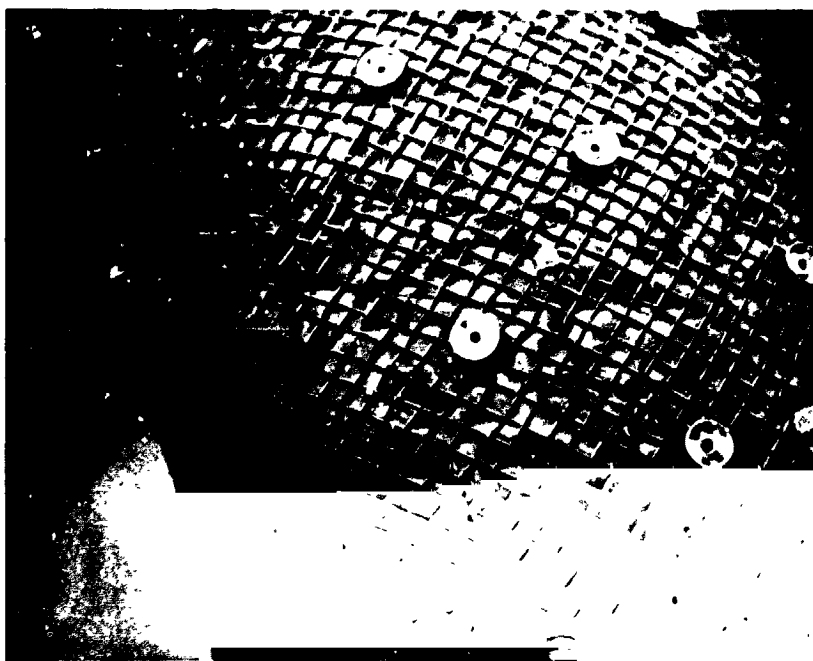


Figure 43 Wheel Design No. 3 after 1,000-Cycle Conditioning;  
Location No. 1



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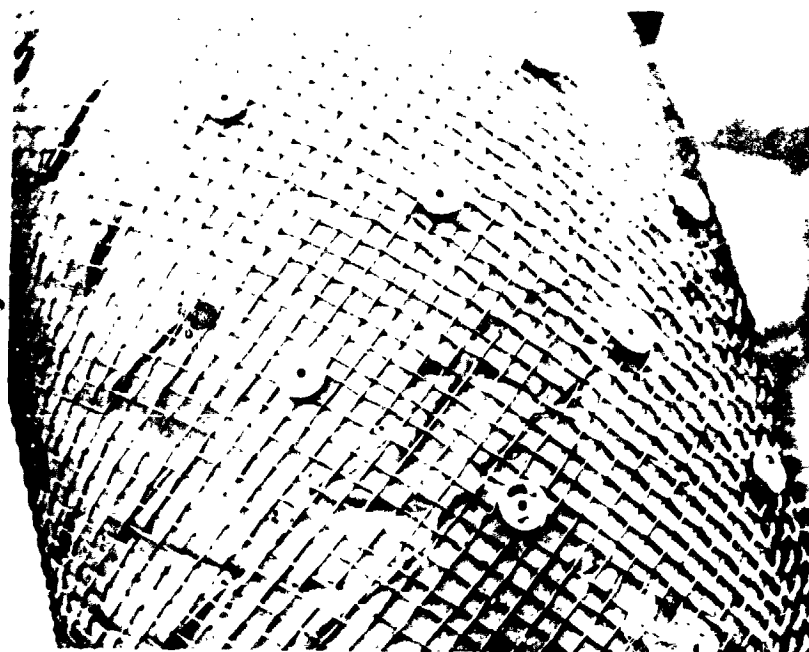


Figure 44 Condition of Wheel Design No. 3 at Location No. 2 after 1,000-Cycle Conditioning

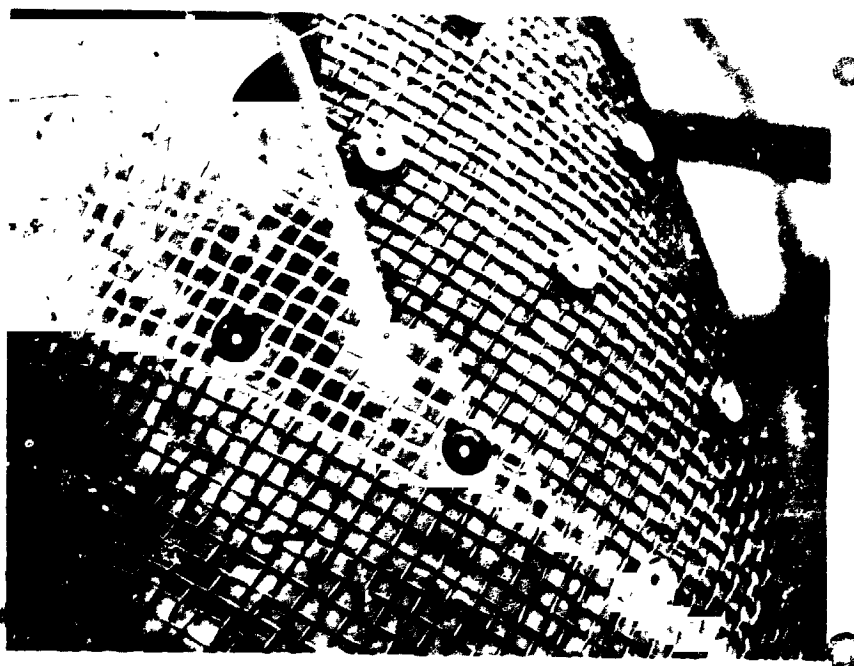


Figure 45 Condition of Wheel Design No. 3 at Location No. 3 after 2,597 Cycles of Smooth Surface Endurance Testing

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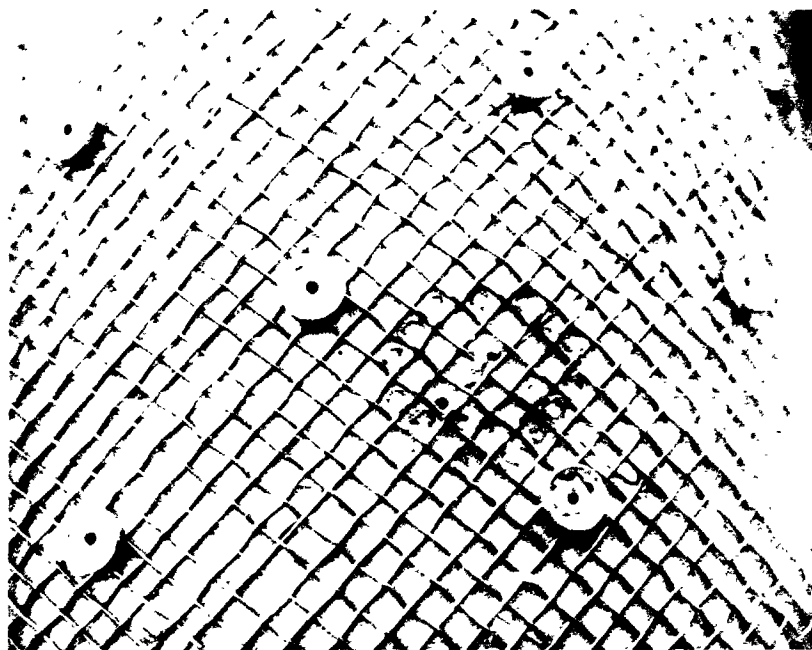


Figure 46 Wheel Design No. 3 at Location 4 after 5,000 Cycles of Smooth Surface Testing

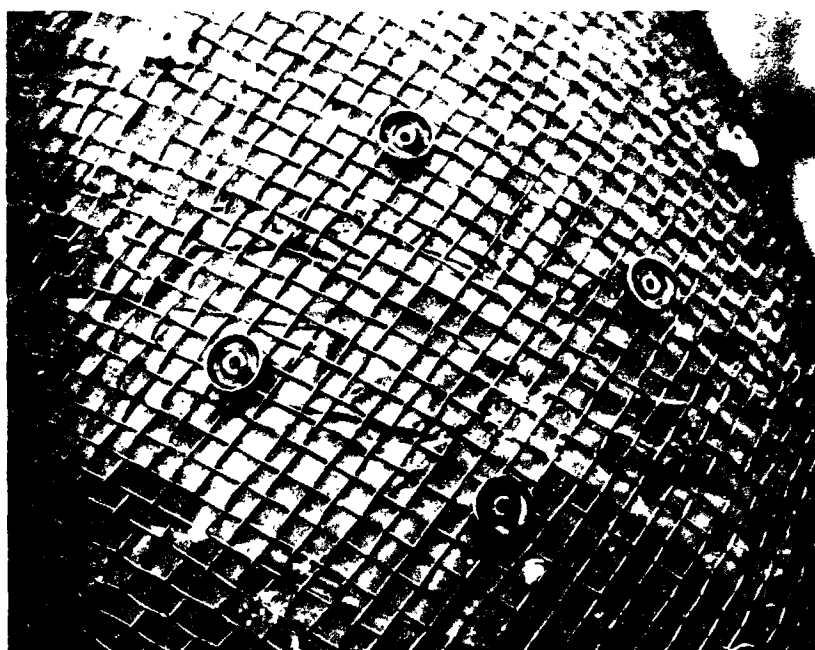


Figure 47 Condition of Wheel Design No. 3 at Location 1 after 7,138 Cycles of Smooth Surface Endurance Testing

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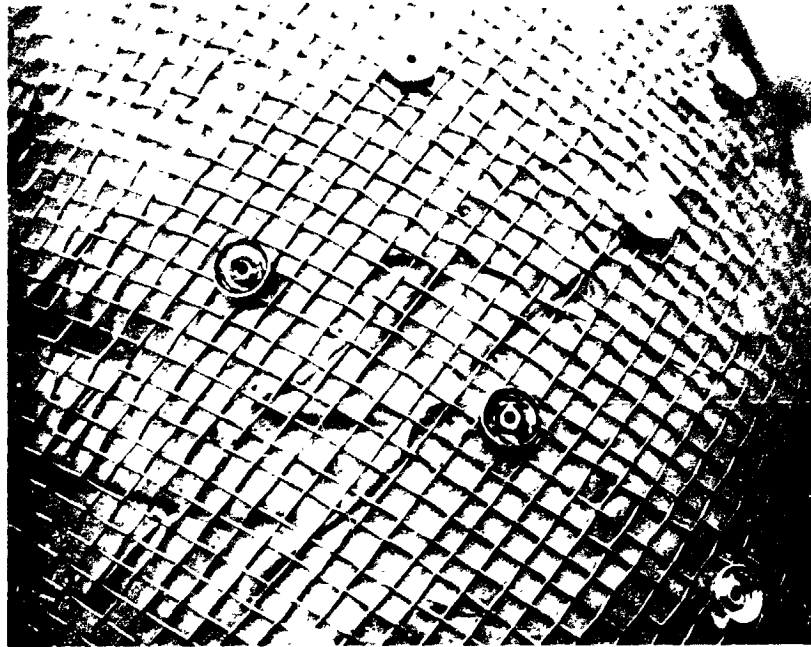


Figure 48 Wheel Condition of Design No. 3 at Location No. 2 after 7,138 Cycles of Smooth Surface Endurance Testing

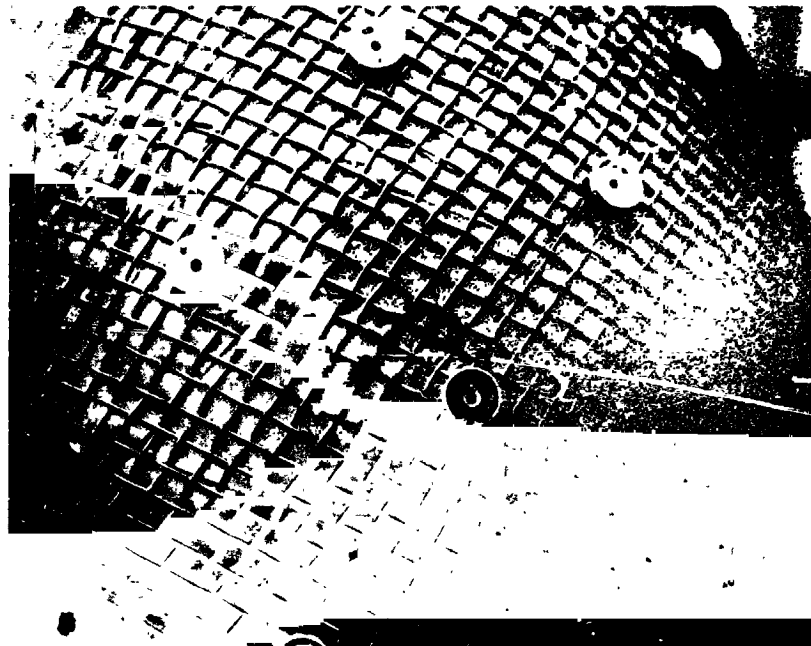


Figure 49 Wheel Condition of Design No. 3 at Location 3 after 7,138 Cycles of Smooth Surface Endurance Testing

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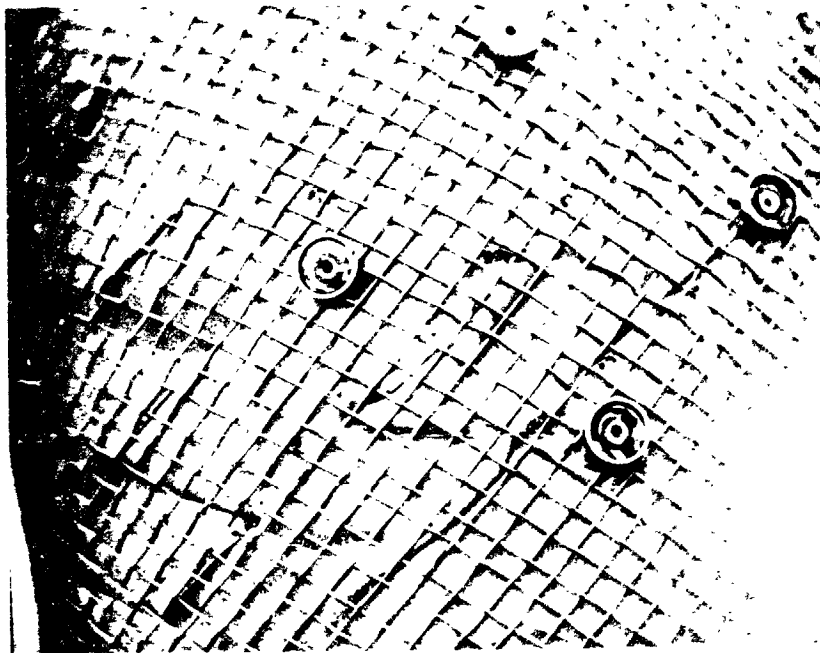


Figure 50 Wheel Condition of Design No. 3 at Location No. 1 after 29,385 Cycles of Smooth Surface Endurance Testing

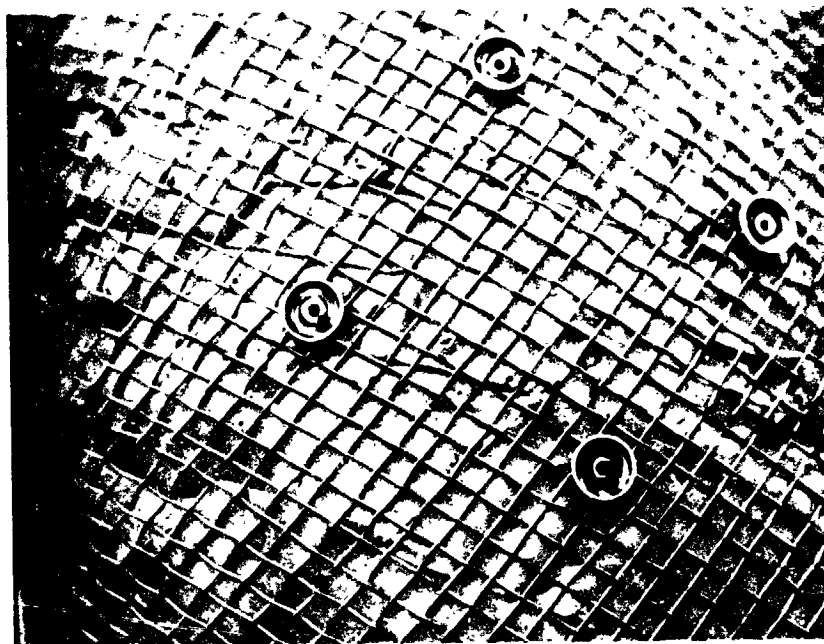


Figure 51 Wheel Condition of Design No. 3 at Location No. 2 after 29,385 Cycles of Smooth Surface Endurance Testing

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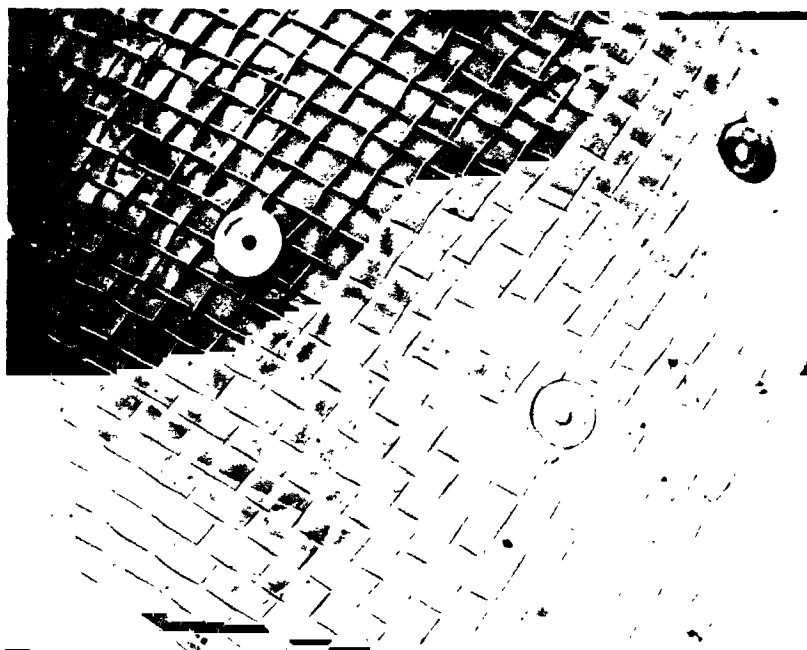


Figure 52 Wheel Condition of Design No. 3 at Location No. 3 after 29,385 Cycles of Smooth Surface Endurance Testing

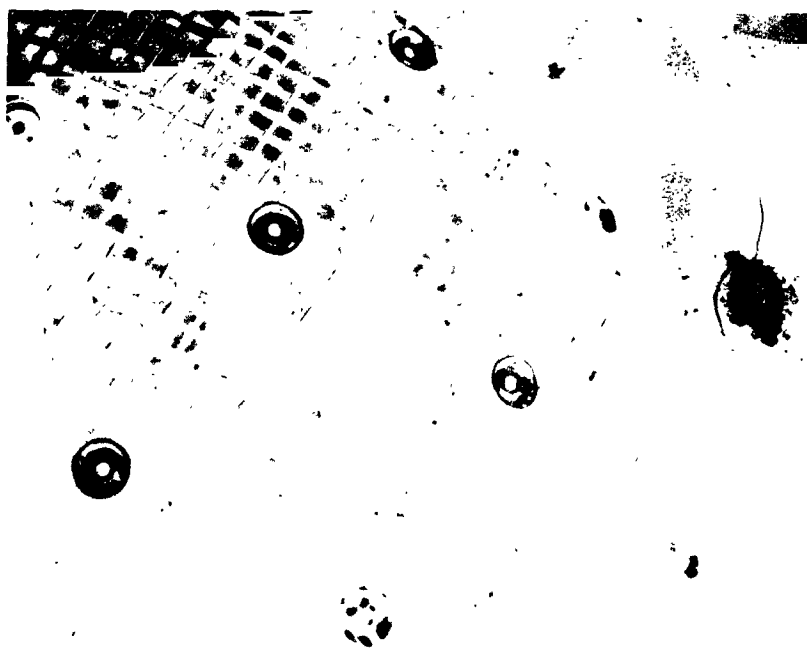


Figure 53 Wheel Condition of Design No. 3 at Location No. 4 after 29,385 Cycles of Smooth Surface Endurance Testing

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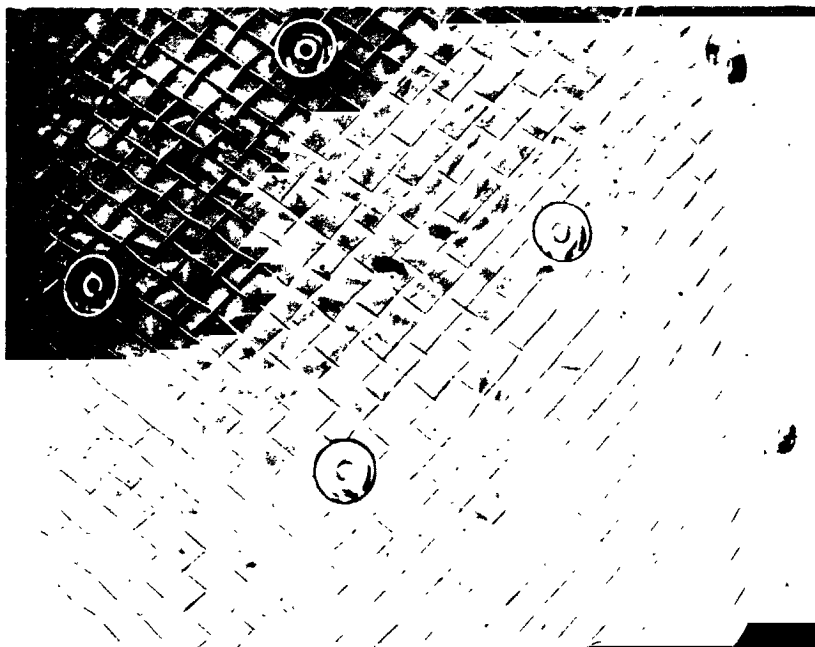


Figure 54 Wheel Condition of Design No. 3 at Location No. 1 after 50,000 Cycles of Smooth Surface Endurance Testing

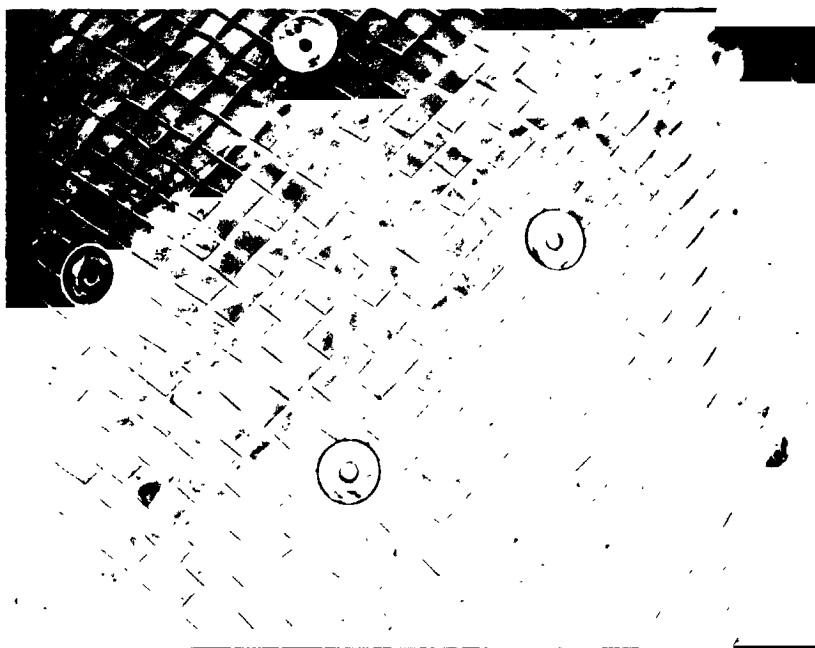


Figure 55 Wheel Condition of Design No. 3 at Location No. 2 after 50,000 Cycles of Smooth Surface Endurance Testing

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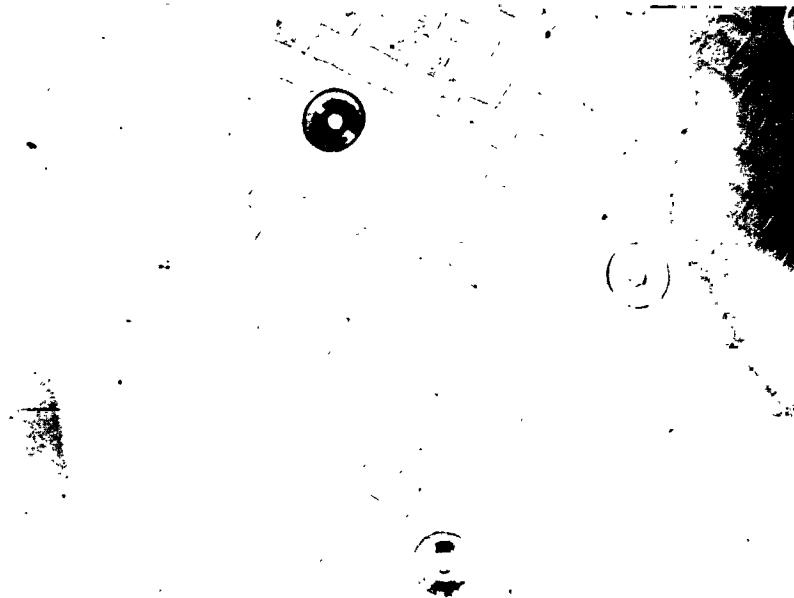


Figure 56 Wheel Condition of Design No. 3 at Location No. 3 after 50,000 Cycles of Smooth Surface Endurance Testing

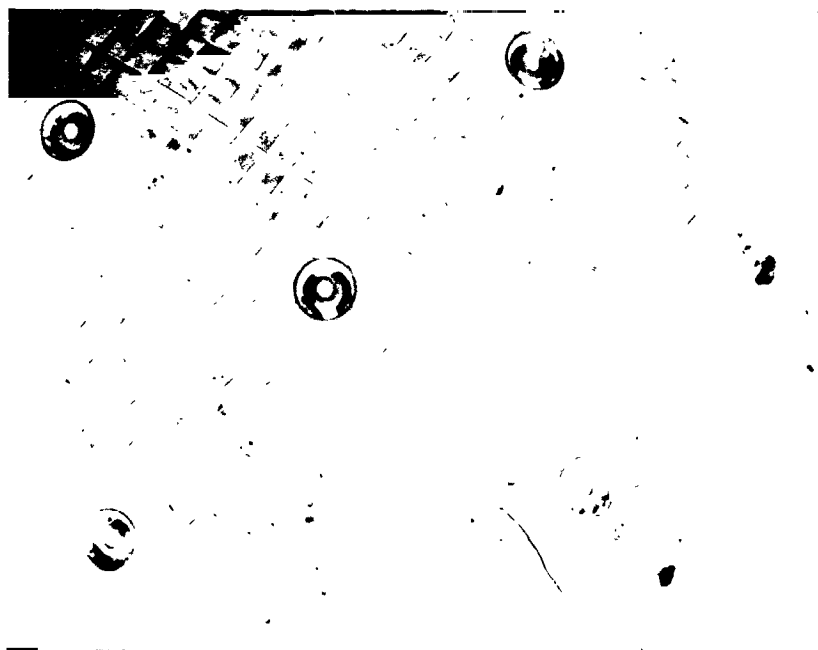
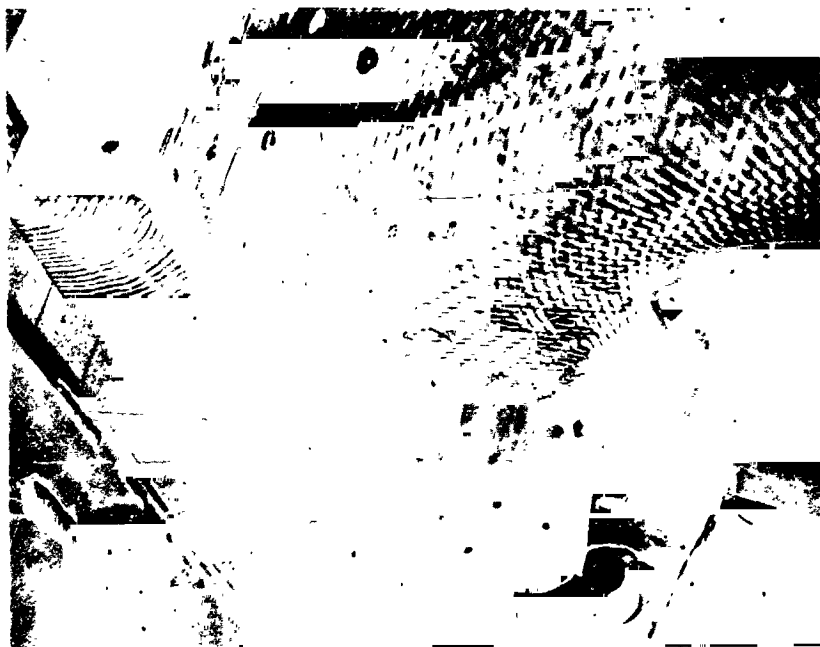
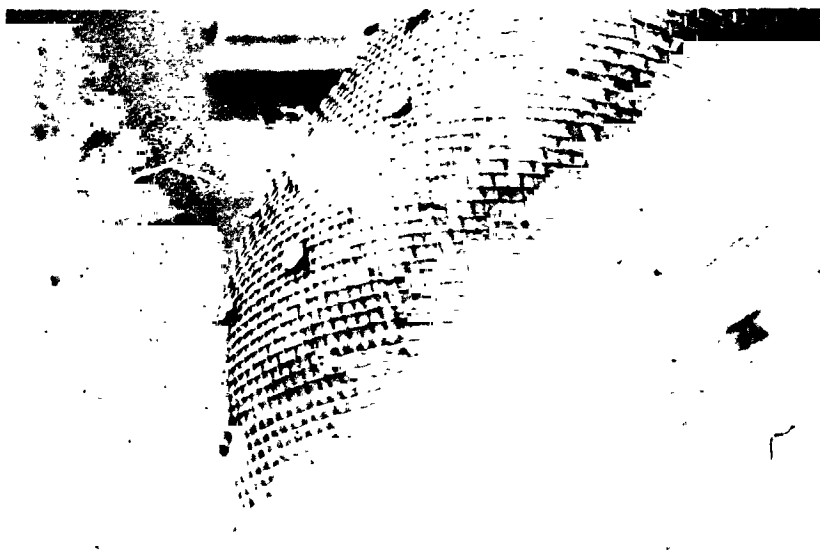


Figure 57 Wheel Condition of Design No. 3 at Location No. 4 after 50,000 Cycles of Smooth Surface Endurance Testing

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**Figure 58** Wheel Design No. 3 Failure after 33 Cycles in Obstacle Endurance Test; Wire Mesh Separates from Rim



**Figure 59** Failure of Wheel Design No. 3 after 33 Cycles in Obstacle Endurance Test; Wire Mesh Separates from Rim



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# TEST REPORT

G M Defense Research Laboratories General Motors Corporation

Report No. \_\_\_\_\_  
Test Reg. No. \_\_\_\_\_  
Date \_\_\_\_\_  
Page \_\_\_\_\_ of \_\_\_\_\_

TITLE: OBSTACLE PATTERN FOR TEST wheel

Prepared by: \_\_\_\_\_ Approved by and Date: \_\_\_\_\_

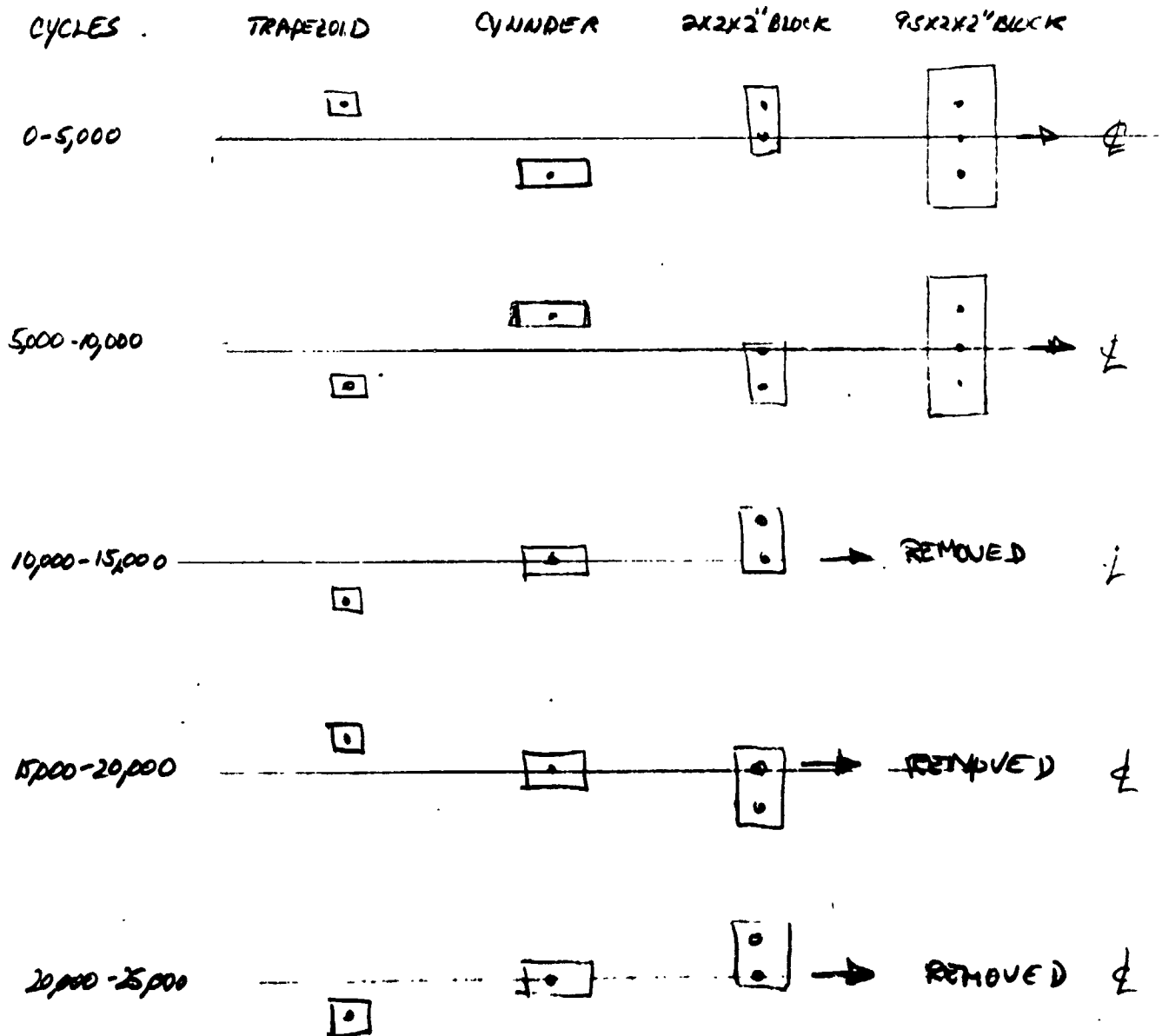


Figure 60 Obstacle Pattern for Obstacle Endurance Test of Wheel  
Design No. 3

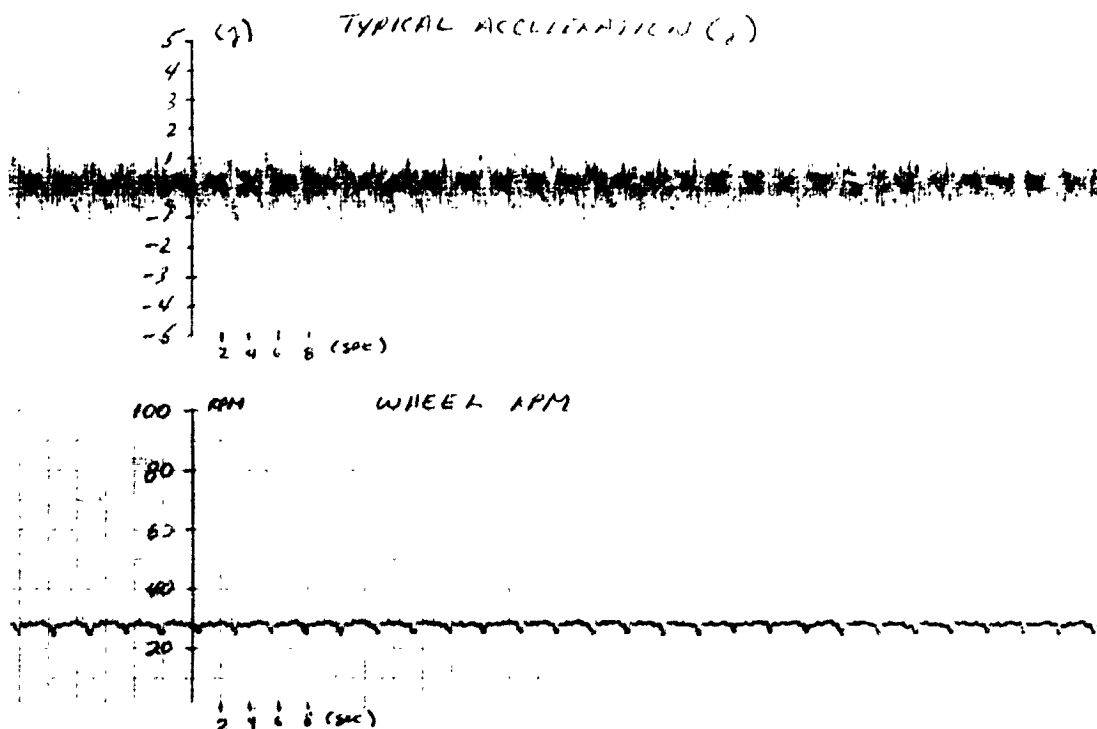
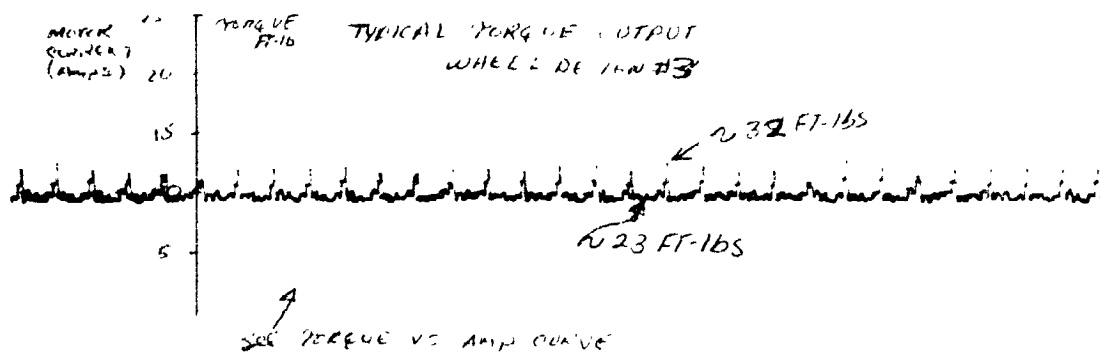
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Figure 61 Typical Recording of Torque, Acceleration and Wheel Velocity During Obstacle Endurance Test of Wheel Design No. 3

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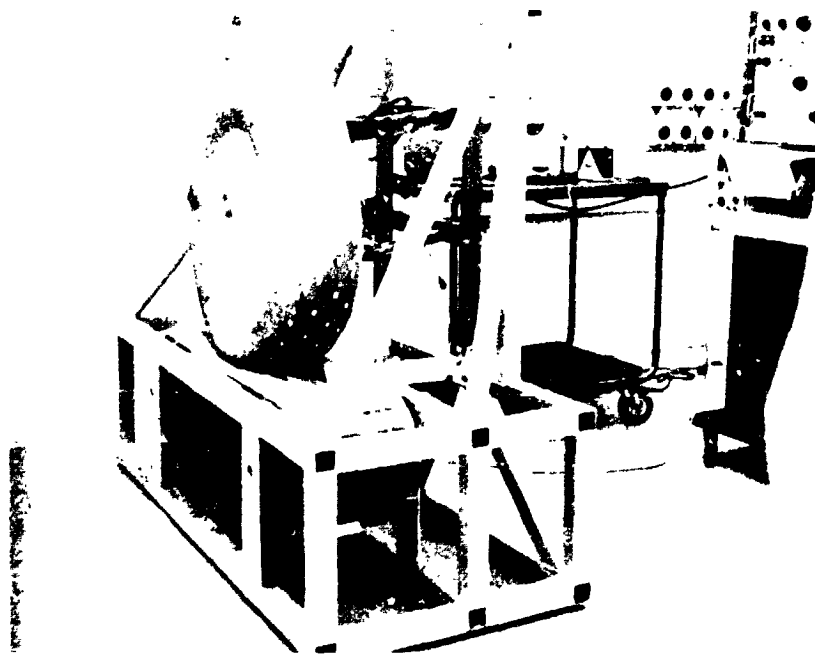


Figure 62 Obstacle Test Setup for Wheel Design No. 3

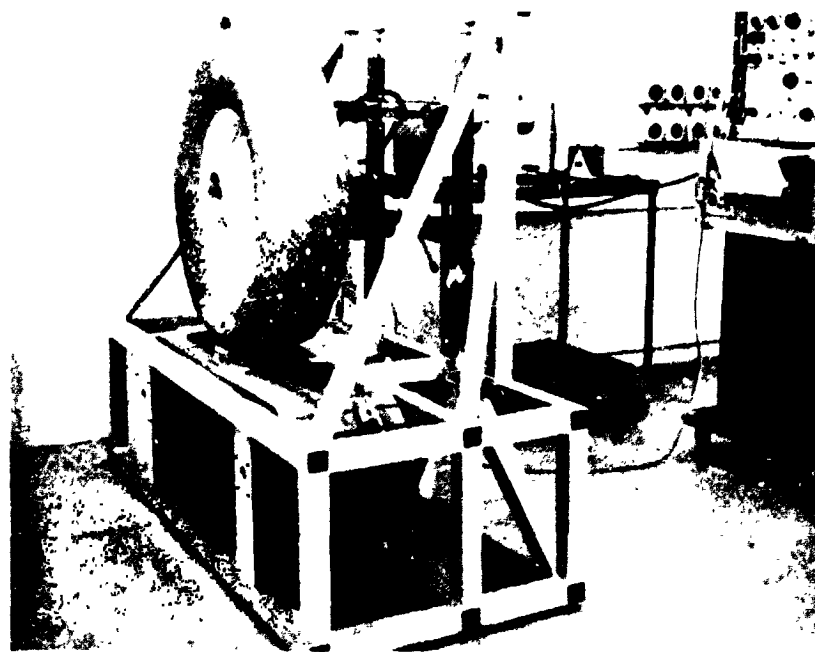


Figure 63 Obstacle Test Setup for Wheel Design No. 3

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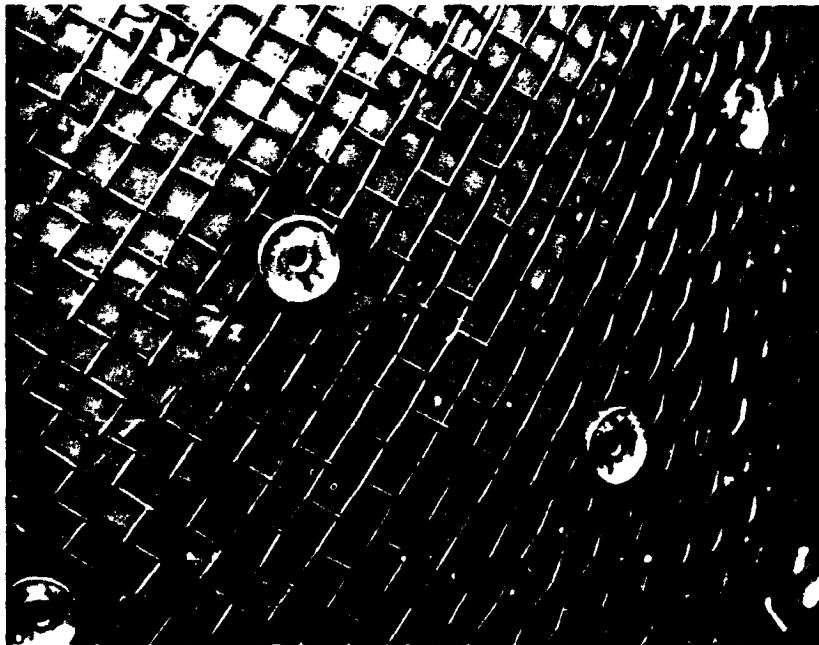


Figure 64 Typical Condition of Wheel Design No. 3 after 10,033 Cycles of Obstacle Endurance Testing



Figure 65 Typical Condition of Wheel Design No. 3 after 10,033 Cycles of Obstacle Endurance Testing

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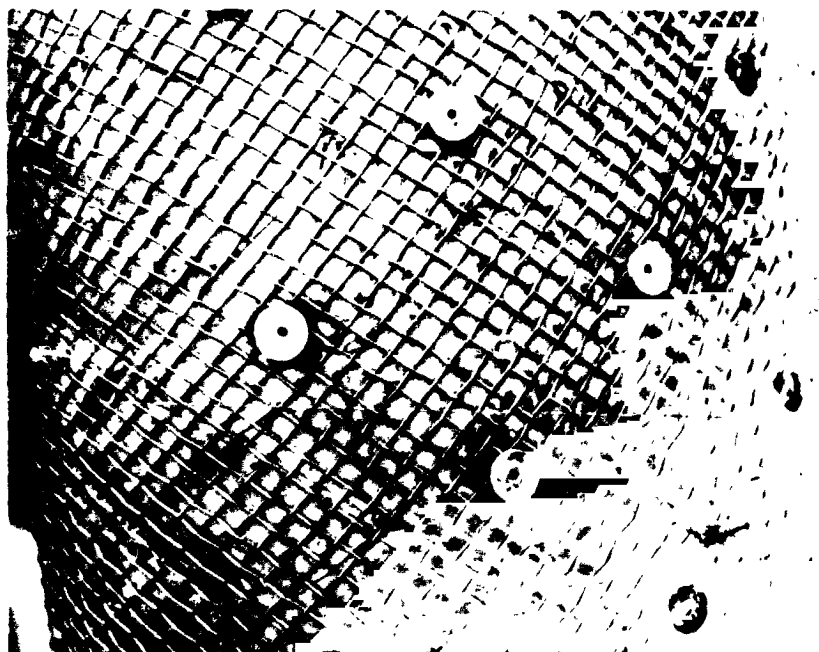


Figure 66 Typical Condition of Wheel Design No. 3 after 15,001 Cycles of Obstacle Endurance Testing

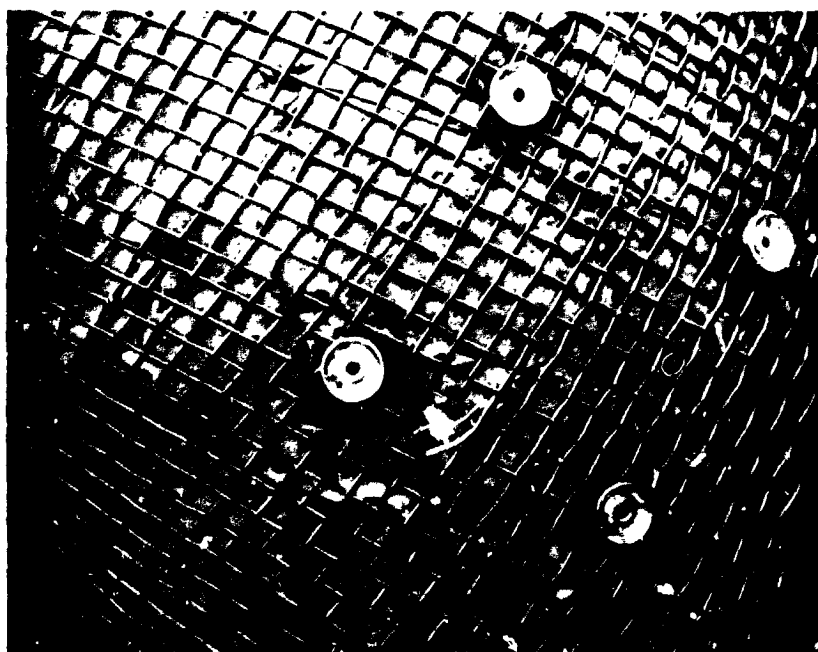


Figure 67 Typical Condition of Wheel Design No. 3 after 20,030 Cycles of Obstacle Endurance Testing

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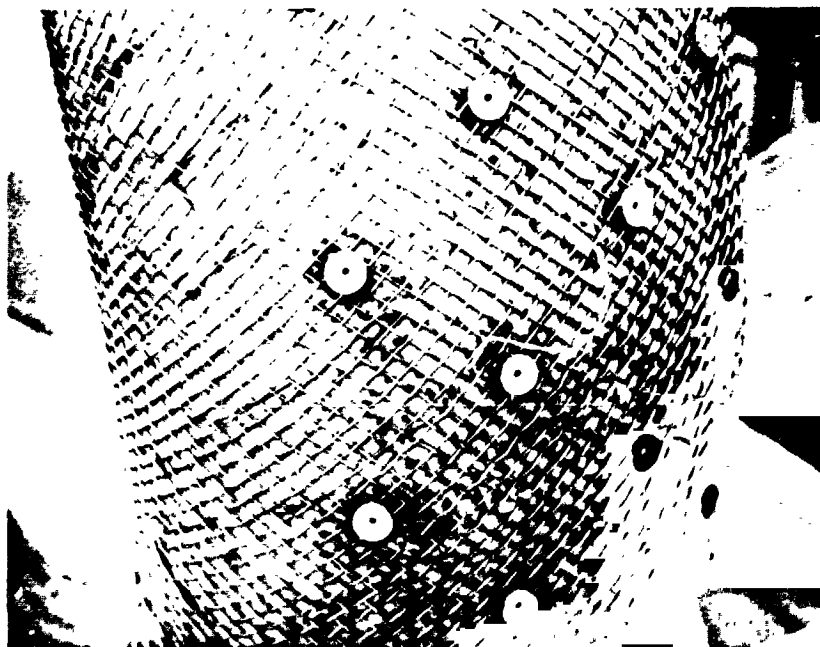


Figure 68 Typical Condition of Wheel Design No. 3 after 25,000 Cycles of Obstacle Endurance Testing

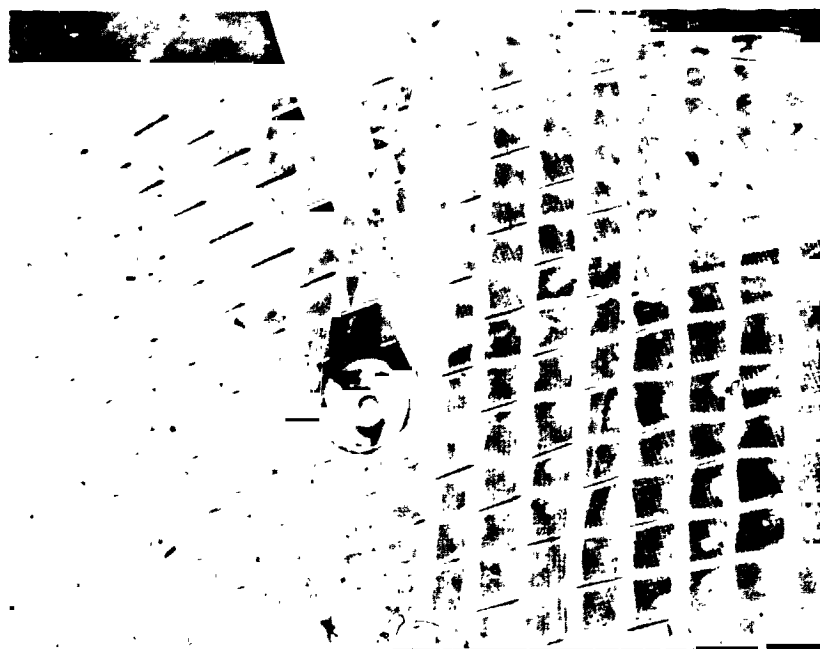


Figure 69 Wire Breakage During Obstacle Testing of Wheel Design No. 3

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Figure 70 Typical Condition of Wheel Design No. 4 at Beginning of Smooth Surface Endurance Test

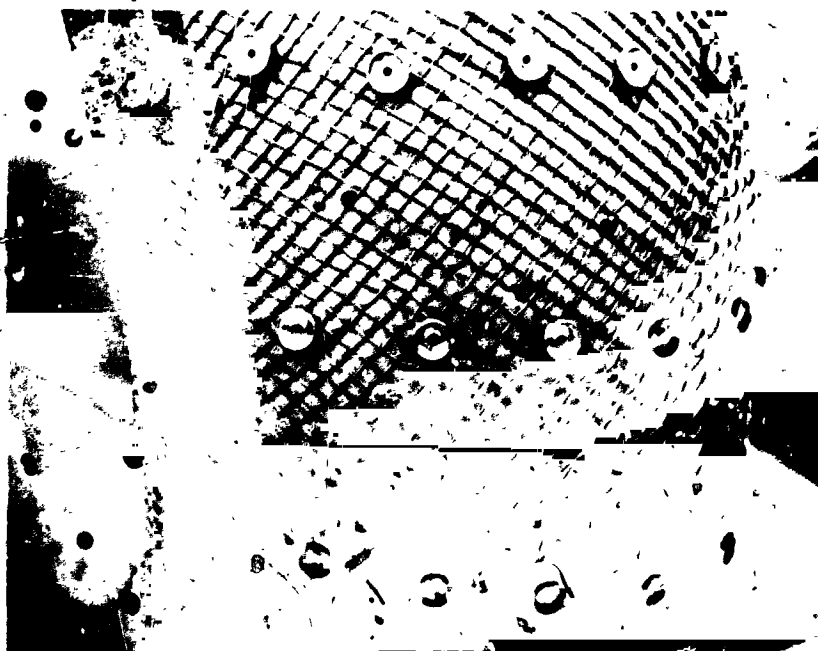


Figure 71 Typical Condition of Wheel Design No. 4 after 5,000 Cycles in Smooth Surface Endurance Testing

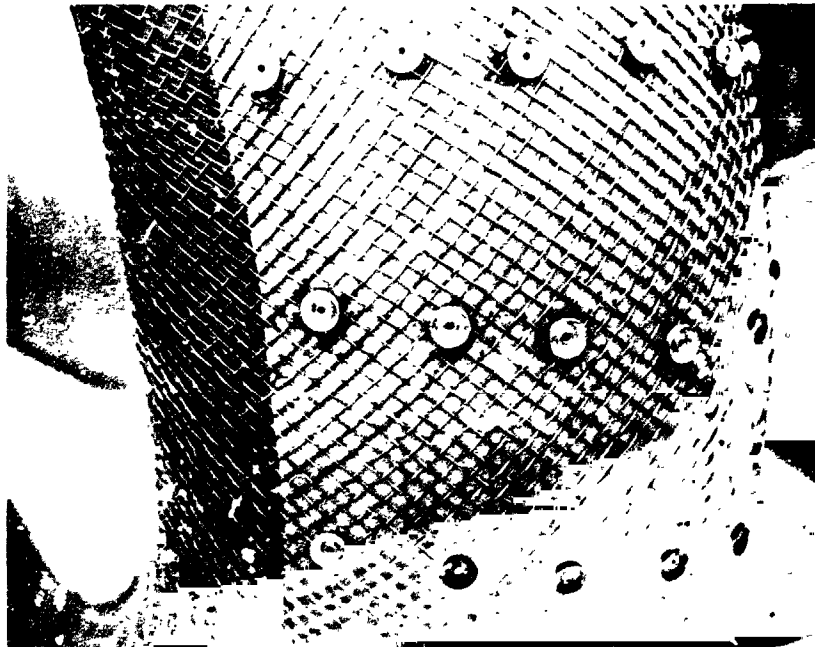


Figure 72 Typical Condition of Wheel Design No. 4 after 15,000 Cycles in Smooth Surface Endurance Testing

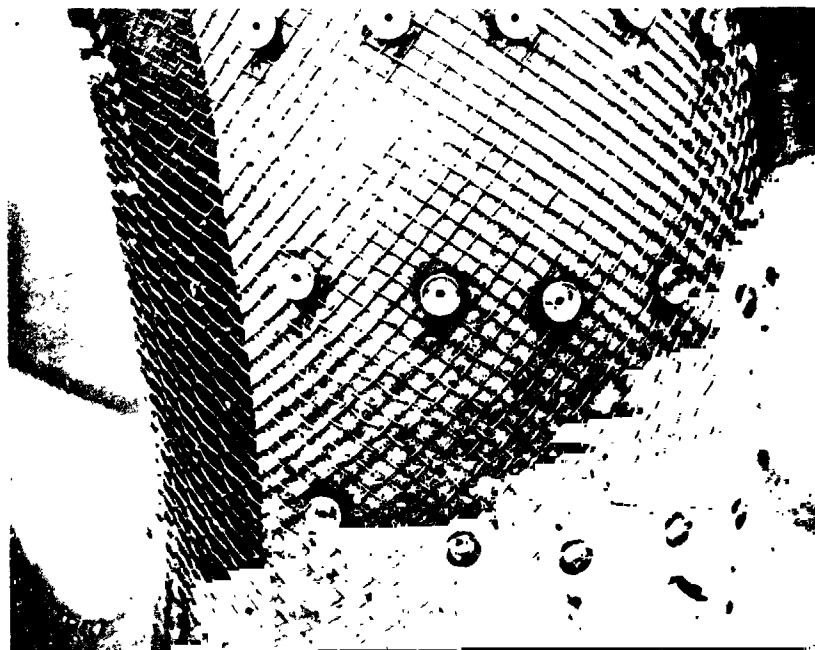


Figure 73 Typical Condition of Wheel Design No. 4 after 25,194 Cycles in Smooth Surface Endurance Testing



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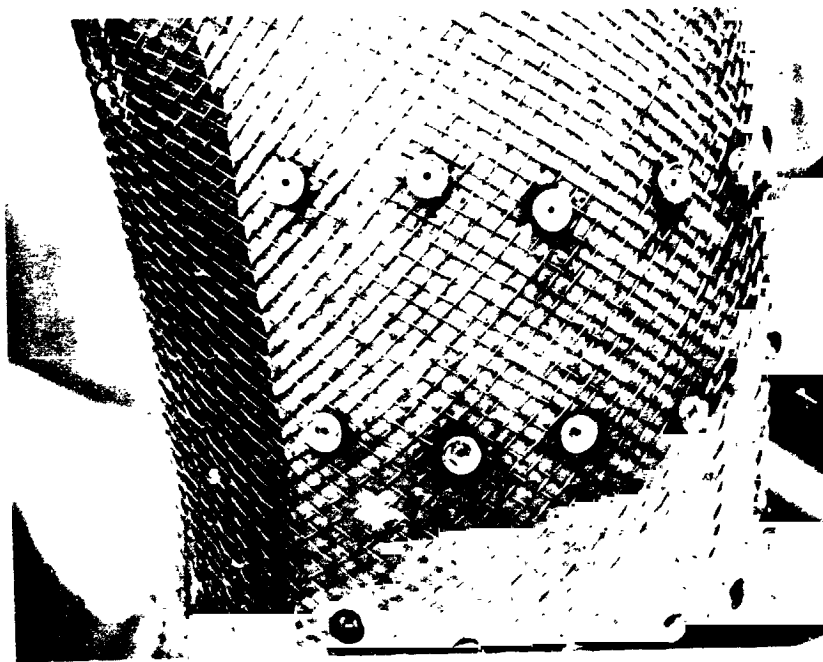


Figure 74 Typical Condition of Wheel Design No. 4 after 40,065 Cycles  
in Smooth Surface Endurance Test

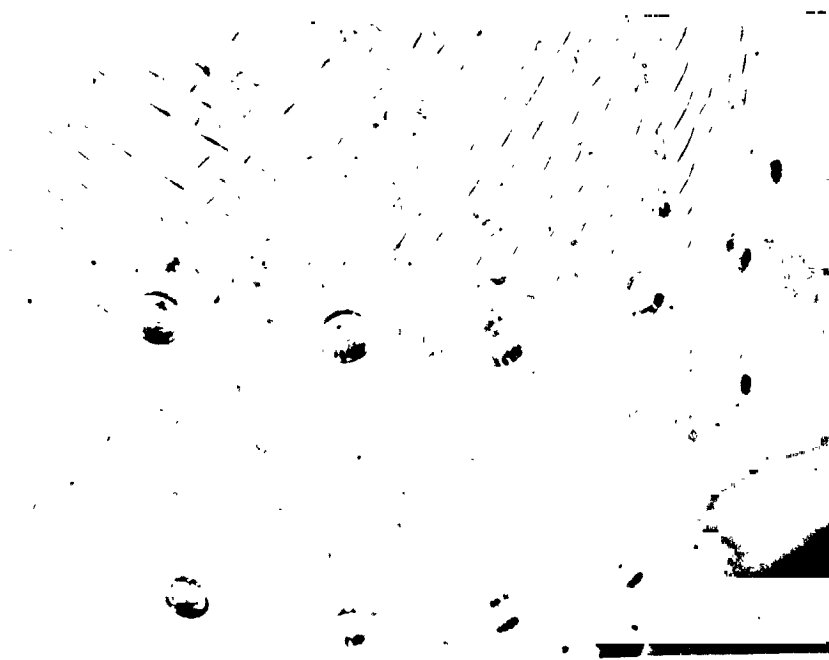


Figure 75 Typical Condition of Wheel Design No. 4 after 50,063 Cycles  
in Smooth Surface Endurance Test

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Obstacle endurance test was performed on the semi-enclosed wheel. During the test the wheel was subjected to a 60 lb wheel load and a 28.5 rpm wheel speed. The torque, vertical acceleration, and velocity of the wheel were recorded during the test. Figure 76 shows a typical recording of torque, vertical acceleration, and wheel speed. The wheel failed after 5,000 cycles. The failure consisted of a considerable amount of wire breakage (see Figure 77 and 78). During the 5,000 cycle inspection, holes 1 CM in diameter were noticed at the location of the inner button cleats (nearest the motor). Closer inspection of the wheel in this area revealed many broken wires under the button cleats. A rough count revealed approximately 50 broken wires in the outer wire mesh. There was also a large number of broken wires on the inner wire mesh. Most broken wires are located on or near the innermost row of cleats (vehicle side of wheel).

The single mesh open wheel configuration endurance test on the rolling road commenced on 20 February with a 1,000 cycle "break-in" run on the smooth road. It was planned to run the wheel for 50,000 cycles at 80 rpm, stopping after every 5,000 cycles for inspection of the wheel. The wheel was loaded with 42 1/2 lbs producing a wheel deflection of 1 3/4 inches. At the end of 5,034 cycles the deflection was found to be 1 7/8 inches and the load was lightened to 40 lbs, to once again give a wheel deflection of 1 3/4 inches. No further changes were made in wheel loading throughout the endurance test.

The endurance test continued with stops about every 5,000 cycles. Between the 44,313 cycle and the 50,004 cycle at which points the wheel was stopped, three wires were broken and were found at the latter stop. An additional broken wire was found at the inspection stop after 60,317 cycles and another after 65,286 cycles. All broken wires occurred at high spots on the tire. Figure 79 is a photograph of a typical broken wire found during the endurance testing.

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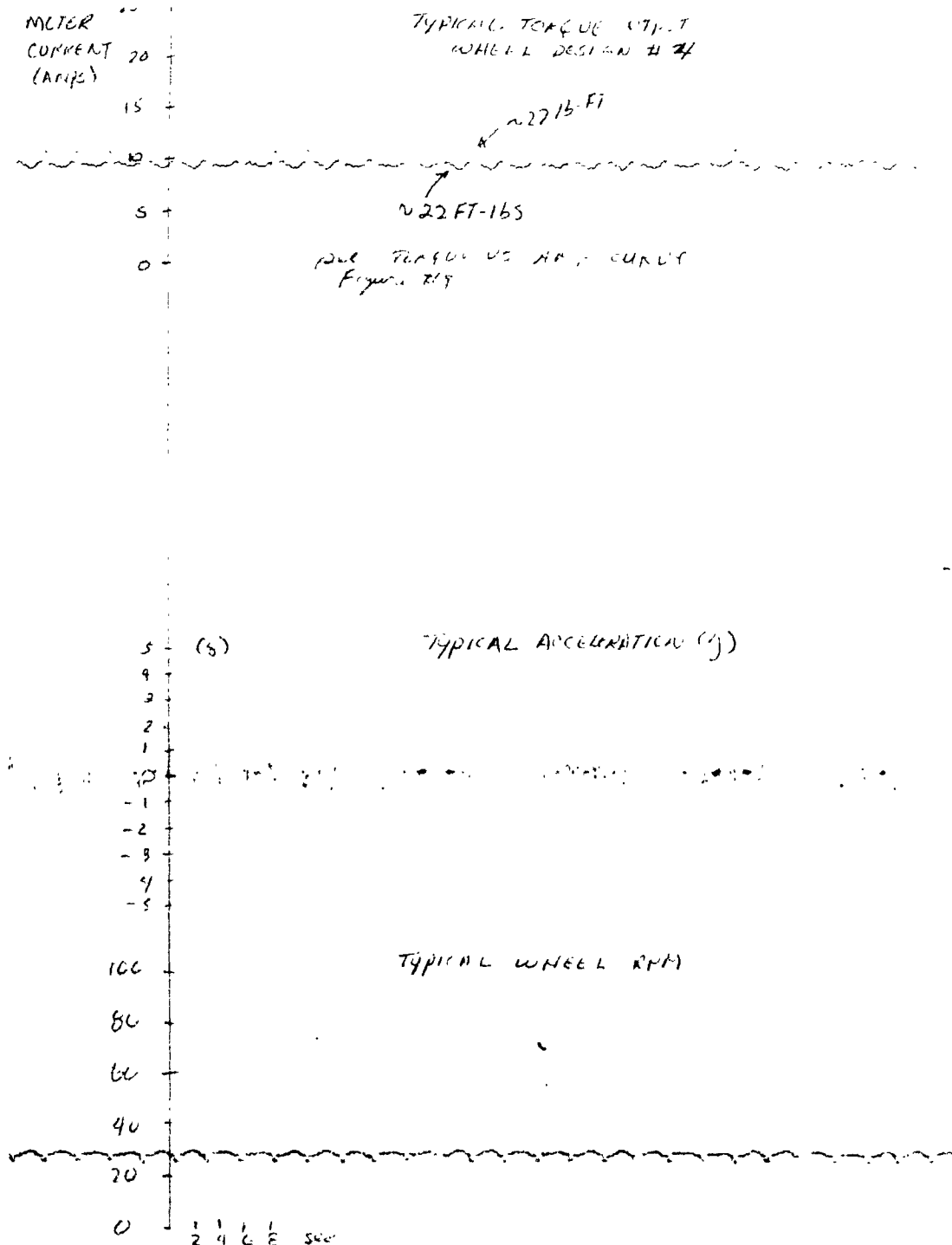


Figure 76 Typical Recording of Torque, Acceleration, and Wheel Velocity During the Obstacle Endurance Test of Wheel Design No. 4



Figure 77 Wire Breakage in Wheel Design No. 4 after 5,000 Cycles in Obstacle Endurance Test

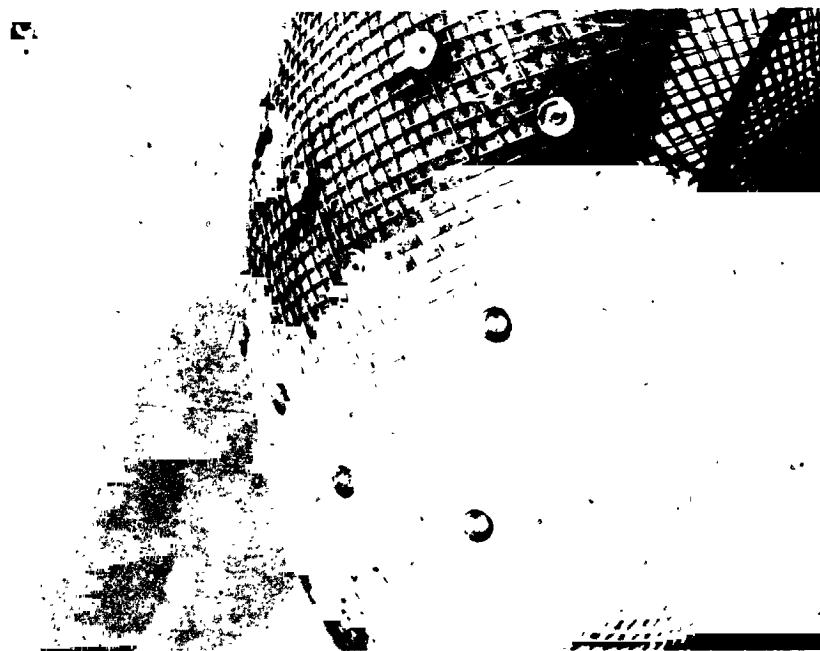


Figure 78 Wire Breakage in Wheel Design No. 4 after 5,000 Cycles in Obstacle Endurance Test

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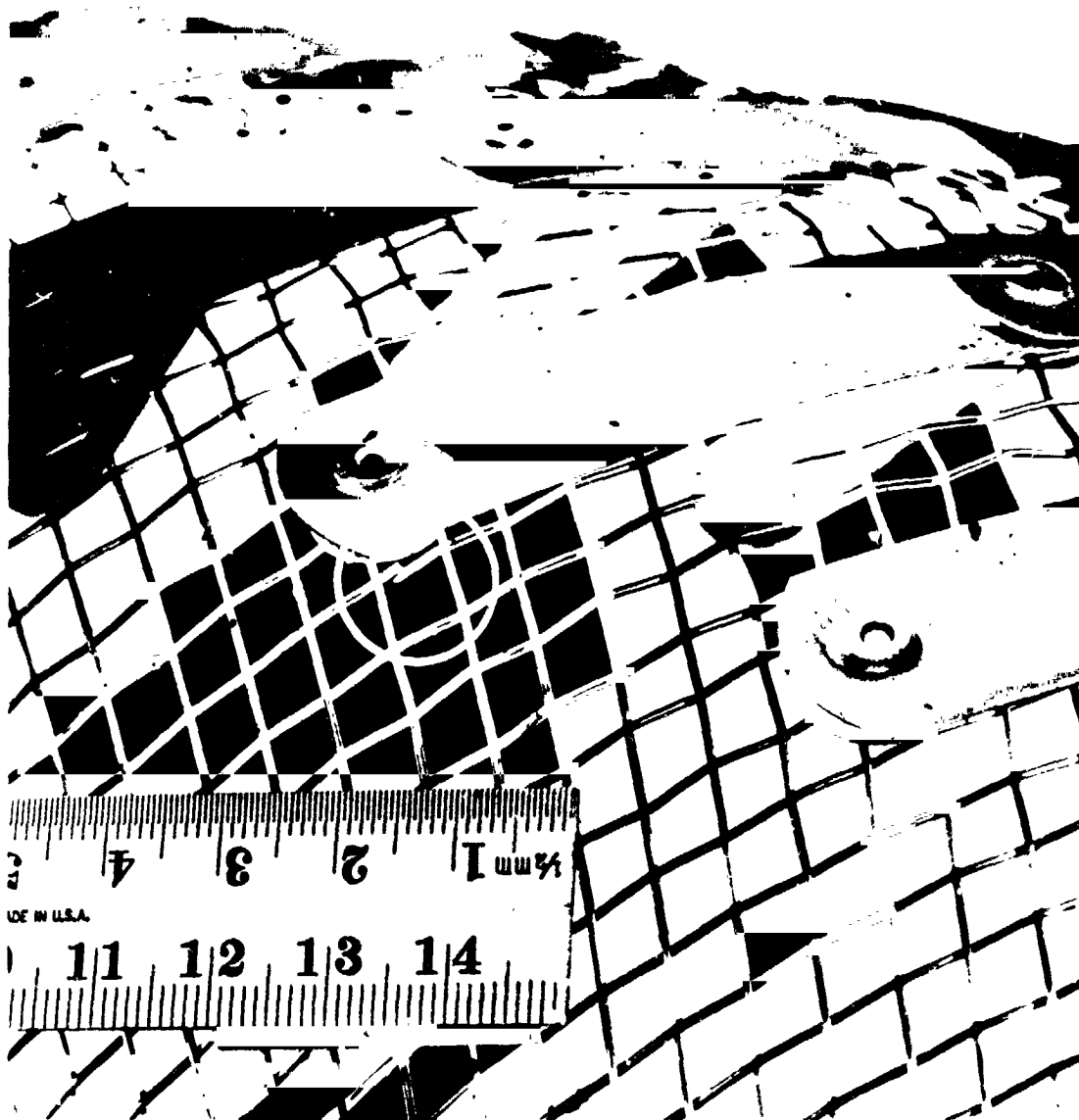


Figure 79 Typical Wire Breakage — Open-Wheel Configuration

## SECTION V

### TEST CONCLUSIONS AND RECOMMENDED DLRV WHEEL CONFIGURATION

#### 5.1 Summary of Conclusions

- Based on the results of the soft soil performance tests, it was shown that both the open and closed wheels can meet the requirements. The open wheel has lower draw-bar pull (slope climbing) capability in loose soil due to its higher ground pressure and tendency to "dig in" at high wheel slip.
- Endurance tests indicated that a double mesh, fully enclosed wheel can be developed to meet DLRV life requirements. There is, however, a 1.0 to 1.8 lb/wheel weight penalty associated with the wheel enclosure.
- Endurance tests have shown that the button cleats used as grousers for the closed-type wheels result in local stress concentration and early fatigue failure of the wire mesh.
- Load-deflection tests indicated that the stiffness of the covered wheel increased by up to 50% after soil bin testing, due to increased friction between the fabric and the wire mesh caused by the sand. No change in stiffness was found for the open wheel.
- The closed wheel has shown lower locomotion efficiency up to a Drawbar Pull/Weight (P/W) ratio of approximately 0.5. This is attributed to the higher mechanical losses associated with flexing the fabric. At high P/W ratio (associated with high slip), the losses of the open wheel due to "dig in" offset the higher mechanical efficiency.
- A summary of the advantages and disadvantages of a completely enclosed wheel is given below:

#### Advantages

- Better flotation and higher P/W in soft soil
- Prevention of loose soil getting inside wheel rims

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#### Disadvantages

- Higher weight
- Mechanical complexity associated with double wire mesh and fabric cover
- Higher mechanical rolling resistance
- Variation in wheel stiffness due to soil between wire mesh and fabric
- Inner frame cannot be inspected after wheel is assembled.

#### 5.2 Recommended DLRV Wheel Configuration

An engineering analysis of the test results indicates that of the four design concepts tested, the single woven wire mesh open wheel design with a chevron tread is the best concept for continued development for the Dual Mode vehicle. Although there were several wires broken during the testing it is felt with increased emphasis on material quality control and improved fabrication techniques the wheel could be made to meet the DLRV requirements. The open wheel concept was therefore presented to NASA personnel at an oral presentation at AC-DRL on 5 February 1970. Assembly and detail drawings were formally submitted to NASA on 18 March 1970 for approval. Three wheels were fabricated from the drawings after this approval for test and evaluation by NASA.

The tabulated specifications for the DLRV wheel is shown in Table VI, while the proposed formal specification is contained in ES 10115, Appendix 5 of this report.

#### 5.3 Wheels Fabricated to Recommended Configuration

Three wheels were fabricated in accordance with the contract to the approved drawings for delivery per NASA instructions for test and evaluation. A photograph of one of these wheels, serial number 1, is shown in Figure 80. Figure 81 is a photograph of this wheel during deflection testing. The results of the deflection tests are shown in Figure 82.

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DLRV WHEEL SPECIFICATIONS

Nominal Diameter	32 inches
Nominal Width	9 inches
Nominal Load	57 lb
Nominal Torque	78.0 ft-lb
Limit Radial Load	600 lb
Limit Lateral Load	160 lb
Nominal Deflection	1.75 inches
Nominal Ground Pressure	0.6 psi
Maximum Speed	116 rpm
Life	625,000 rev.



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Figure 80 Final Design of Open-Wheel Configuration Delivered to NASA

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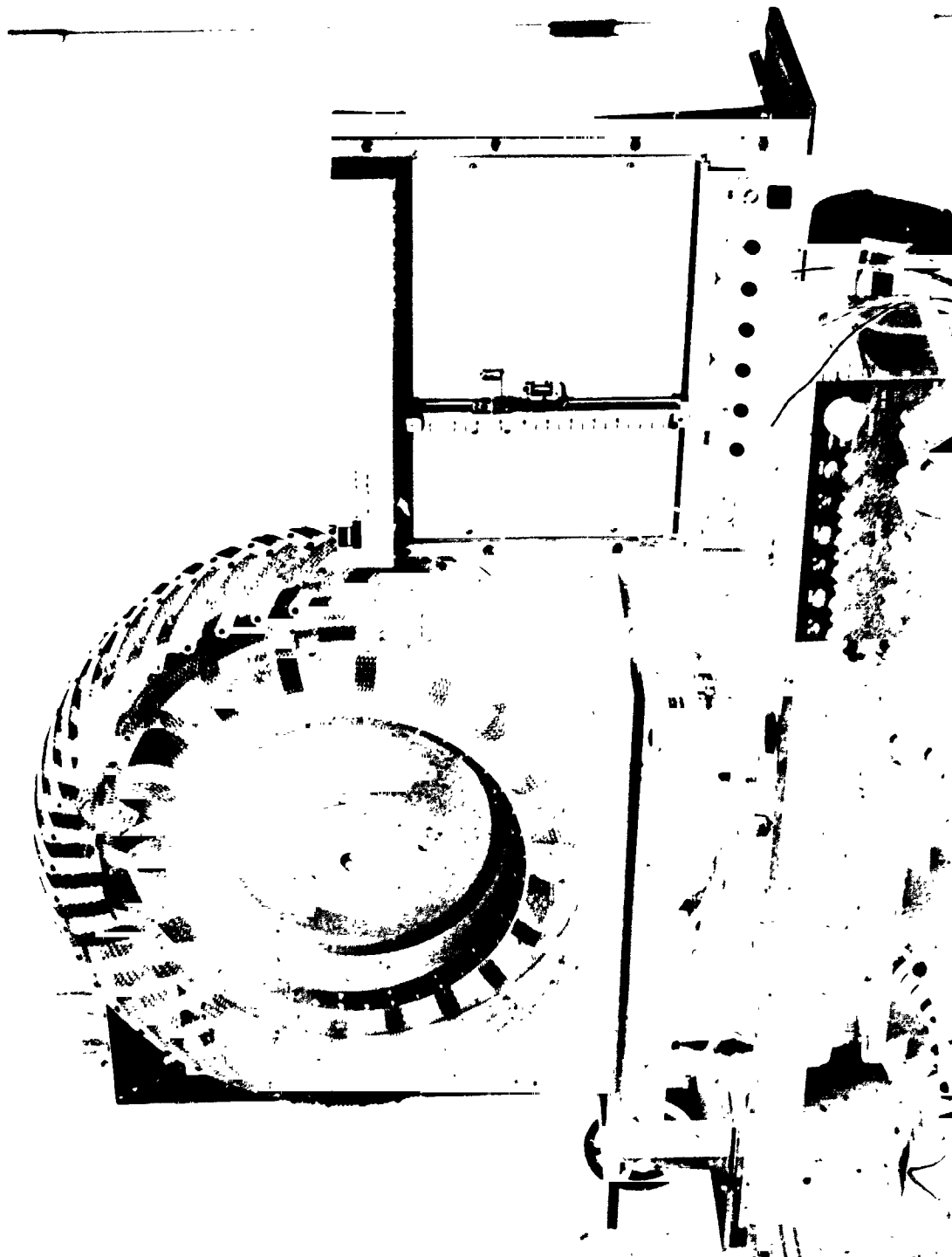


Figure 81 Open-Wheel Configuration Being Static Deflection  
Tested Prior to Shipment

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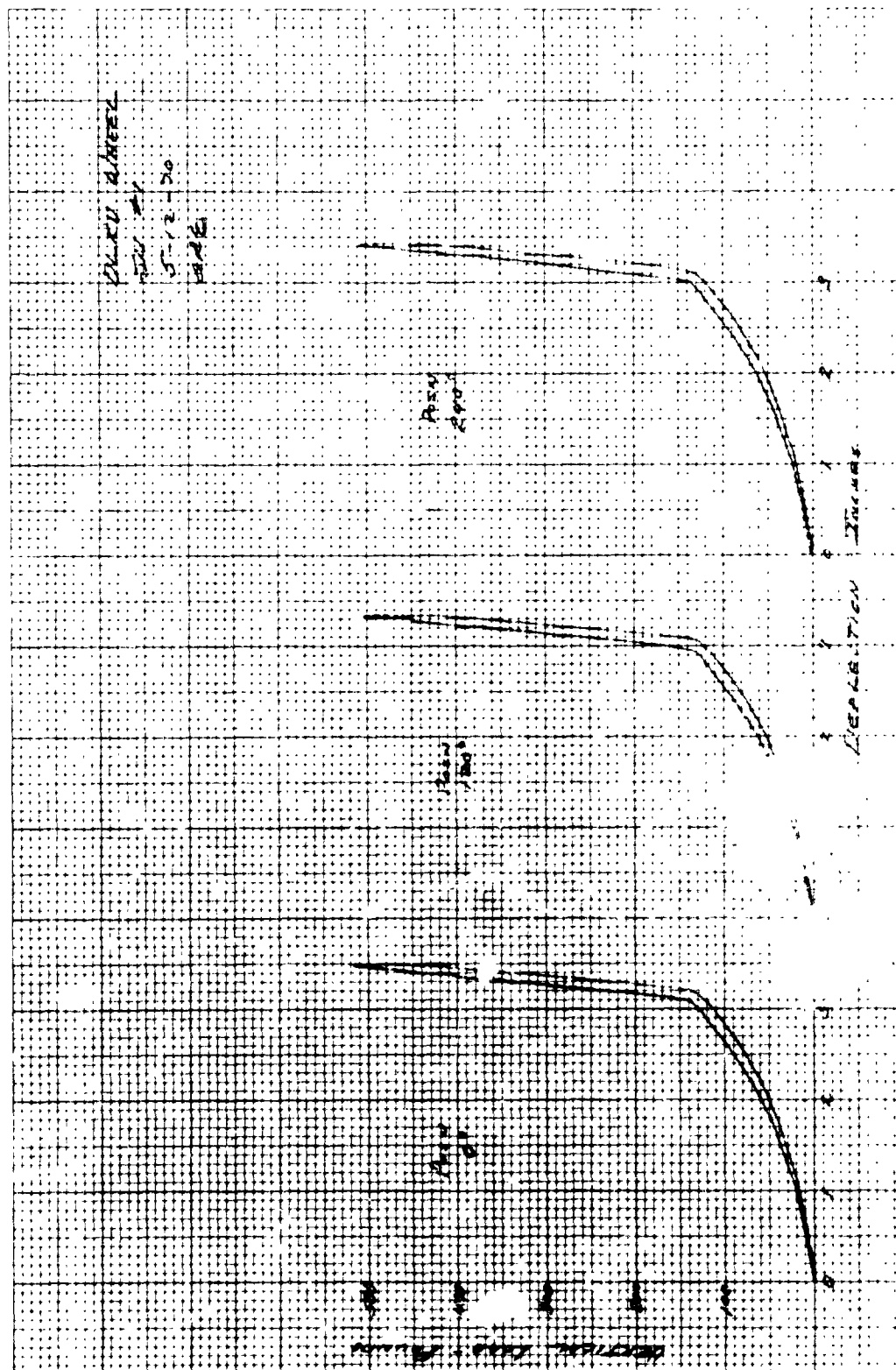


Figure 82 Deflection Test Results

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## SOIL TESTS

Crushed Silica Sand, Air Dry, Loose and Compacted Conditions  
Charts, Calibration, and Analysis

## CONTENTS

<u>Section</u>	<u>Page</u>
Density	1-1 to 1-3
Particle Grain Size Distribution	1-4 to 1-5
Shear Box	1-6 to 1-12
Bevometer Shear Tests	1-13 to 1-17
Plate Penetration Tests	1-18 to 1-23

The following values for the soil density were obtained during each day of testing.

	<u>Wet Density</u>	<u>Dry Density</u>
12-19-69 - loose condition	98.0	97.5
12-19-69 - loose condition	97.3	96.8
12-22-69 - compacted condition	104.9	104.4
12-22-69 - compacted condition	108.4	107.9
12-22-69 - compacted condition	105.6	105.1
12-22-69 - loose condition	95.2	94.7
12-22-69 - loose condition	93.8	93.3
1-7-70 - loose condition	97.3	96.8
1-8-70 - loose condition	96.6	96.1
1-8-70 - loose condition	97.3	96.8
1-8-70 - compacted condition	105.5	105.0
1-8-70 - compacted condition	107.2	106.7
1-9-70 - compacted condition	108.2	107.7
1-9-70 - compacted condition	106.4	105.9

The next two figures show the density calibration sheet and an example of a density calculation sheet.

## FIELD DENSITY TEST - SAND CONE METHOD

Sand Cone Apparatus No. \_\_\_\_\_  
Plate No. \_\_\_\_\_ Date of Calibration 1-6-70  
Sand Designation \_\_\_\_\_ Personnel J. T. GRAY

### CALIBRATION

#### Volume of jar and funnel to valve

- |   |                   |
|---|-------------------|
| 1. Weight of apparatus filled to valve with water   | <u>5681</u> gms.  |
| 2. Weight of apparatus empty  | <u>1656</u> gms.  |
| 3. Weight of water in apparatus to valve<br>(Item 1 - Item 2)                             | <u>4025</u> gms.  |
| 4. Volume of apparatus to valve<br>at <u>20.4</u> °C. ml. of water per gm. <u>1.0019</u>  | <u>4032.65</u> cc |
|   |                   |
| 1a. Weight of apparatus filled to valve with water  | <u>5676</u> gms.  |
| 2a. Weight of apparatus empty   | <u>1656</u> gms.  |
| 3a. Weight of water in apparatus to valve<br>(Item 1a - Item 2a)                          | <u>4020</u> gms.  |
| 4a. Volume of apparatus to valve<br>at <u>24.4</u> °C. ml. of water per gm. <u>1.0028</u> | <u>4031.26</u> cc |
|   |                   |
| 1b. Weight of apparatus filled to valve with water  | <u>5685</u> gms.  |
| 2b. Weight of apparatus empty   | <u>1656</u> gms.  |
| 3b. Weight of water in apparatus to valve<br>(Item 1b. - Item 2b)                         | <u>4029</u> gms.  |
| 4b. Volume of apparatus to valve<br>at <u>13.3</u> °C. ml. of water per gm. <u>1.0006</u> | <u>4031.42</u> cc |
| 5. Average volume of apparatus to valve   | <u>4031.78</u> cc |

#### Bulk Density Determination

- |  |                    |
|--|--------------------|
| 6. Weight of apparatus filled to valve with sand             | <u>7990</u> gms.   |
| 7. Weight of sand in apparatus to valve<br>(Item 6 - Item 2) | <u>6334</u> gms.   |
| 8. Bulk density (Item 7 ÷ Item 5)                            | <u>1.571 gm/cc</u> |
|  |                    |
| 9. Weight of apparatus filled with sand                      | <u>7990</u> gms.   |
| 10. Weight of apparatus and remaining sand                   | <u>6257</u> gms.   |
| 11. Weight of sand in cone and plate                         | <u>1733</u> gms.   |

# FIELD DENSITY TEST - SAND CONE METHOD

Sand Cone Apparatus No. \_\_\_\_\_ Date of Test 12-19-69 Test No. 1

Method of Compaction NONE - LOOSE

Test Location 1<sup>ST</sup> RUN

Type of Compactor CULTIVATE

Area Represented \_\_\_\_\_

Number of Passes 2

Material \_\_\_\_\_

Inspector James T. Gray

Layer Designation \_\_\_\_\_

Thickness \_\_\_\_\_

## Volume of Test Hole

- |   |       |        |
|---|-------|--------|
| 1. Weight of apparatus filled with sand                                 | 8103  | gms.   |
| 2. Weight of apparatus and remaining sand                               | 5699  | gms.   |
| 3. Weight of sand in hole, plate and cone (Item 1 minus Item 2)         | 2404  | gms.   |
| 4. Weight of sand in cone and plate (Item 11 of Calibration data sheet) | 1733  | gms.   |
| 5. Weight of sand in hole (Item 3 minus Item 4)                         | 671   | gms.   |
| 6. Bulk density of sand (Item 8 of calibration data sheet)              | 1.571 | gms/cc |
| 7. Volume of test hole (Item 5 ÷ Item 6)                                | 427   | cc     |

## Wet Density

- |  |      |            |
|--|------|------------|
| 8. Weight of moist soil from hole plus tare                        | 856  | gms.       |
| 9. Weight of tare  | 185  | gms.       |
| 10. Weight of moist soil (Item 8 minus Item 9)                     | 671  | gms.       |
| 11. Wet Density $\frac{\text{Item 10}}{\text{Item 7}} \times 62.4$ | 98.0 | lb/cu. ft. |

## Moisture Content and Dry Density

- |   |       |            |
|---|-------|------------|
| 12. Weight of wet sample plus tare  | _____ | gms.       |
| 13. Weight of dry sample plus tare  | _____ | gms.       |
| 14. Weight of water in sample   | _____ | gms.       |
| 15. Tare Number and Weight No. _____  | _____ | gms.       |
| 16. Weight of dry soil (Item 13 minus Item 15)  | _____ | gms.       |
| 17. Moisture content $\frac{(\text{Item 14})}{(\text{Item 16})} \times 100$ FROM MOISTURE BALANCE | 0.5   | %          |
| 18. Dry Density $\frac{(\text{Item 11})}{(1.0 \text{ plus Item 17})}$                             | 97.5  | lb/cu. ft. |

## Compaction Data

- |   |       |            |
|---|-------|------------|
| 19. Maximum dry density from Proctor Test                                     | _____ | lb/cu. ft. |
| 20. Optimum moisture content from Proctor Test                                | _____ | %          |
| 21. Percent Compaction $\frac{(\text{Item 18})}{(\text{Item 19})} \times 100$ | _____ | %          |
| 22. Specified minimum percent compaction                                      | _____ | %          |

Remarks: \_\_\_\_\_

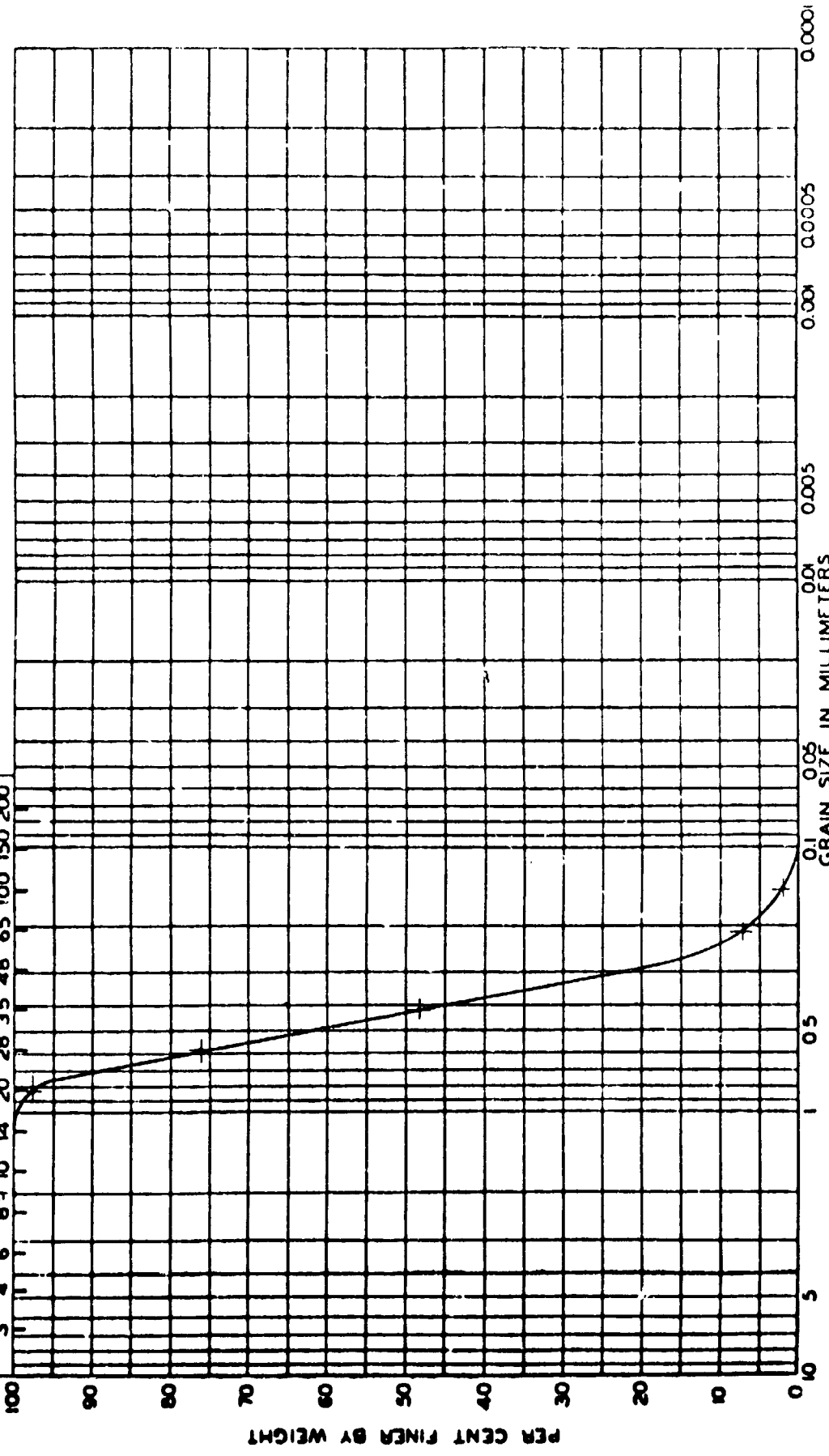
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\_\_\_\_\_

TYLER STANDARD SIEVE NUMBERS  
 3 4 6 8 10 14 20 28 35 48 65 100 150 200

HYDROMETER



MEDIUM GRAVEL	FINE GRAVEL	COARSE SAND	MEDIUM SAND	FINE SAND	VERY FINE SAND	SILT	CLAY
---------------	-------------	-------------	-------------	-----------	----------------	------	------

US BUREAU OF SOILS CLASSIFICATION

PROJECT LRV WHEEL MOBILITY TEST BORING NO 1 SAMPLE NO TEST = 1

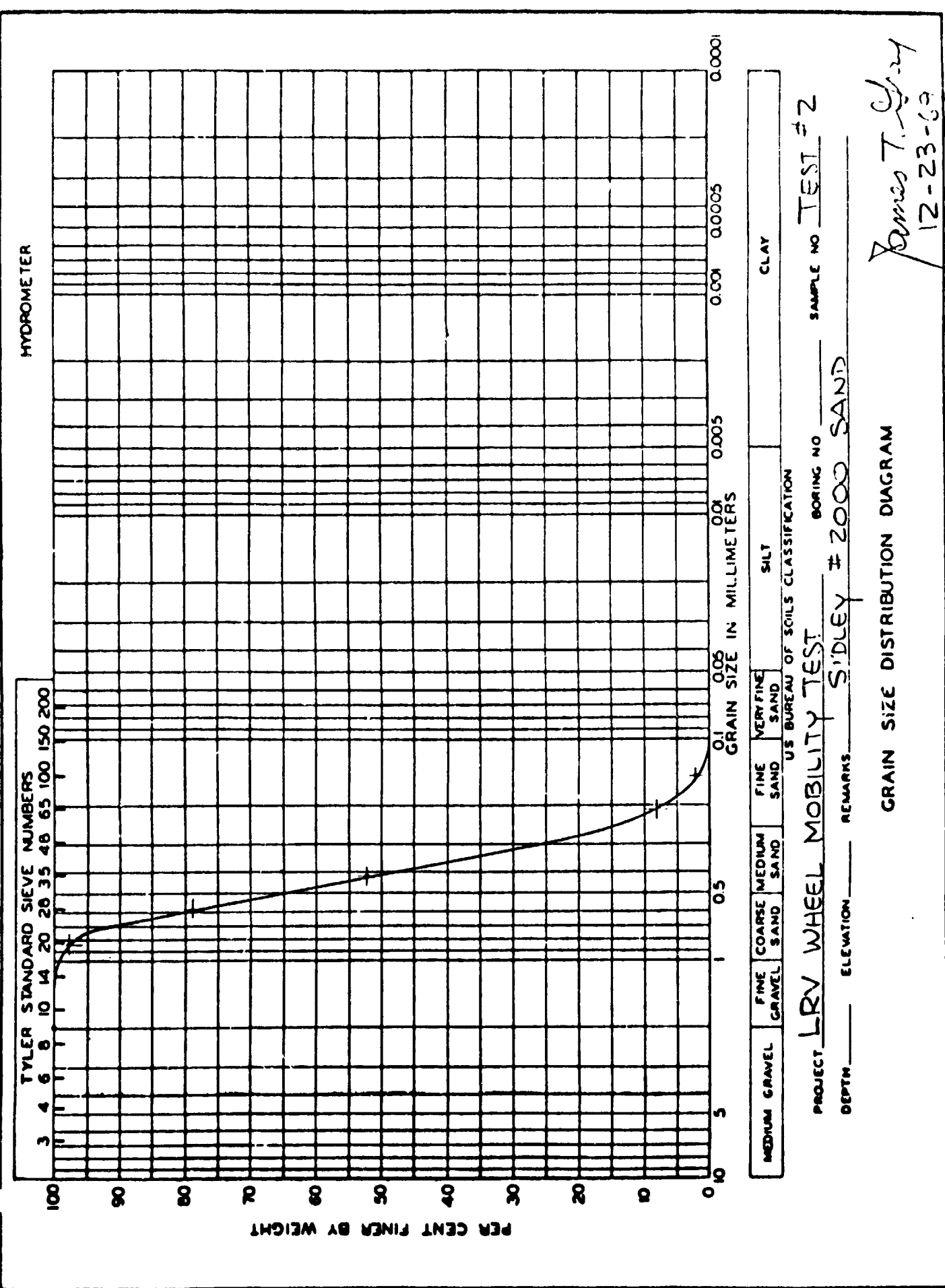
DEPTH            ELEVATION            REMARKS SIDLEY #2000 SAND

GRAIN SIZE DISTRIBUTION DIAGRAM

*Yamamoto*  
 12-23-64

1 DCL-2





J. FRED TRIGGS, JR., P.E.  
5765 MAYFIELD ROAD  
CLEVELAND, OHIO 44124

CONSULTING ENGINEER

January 19, 1970

TEL 216 - 449 4418

General Motors Corporation  
Earthmoving Division  
Engineering Department 940  
Hudson, Ohio 44236

Attention: Mr. J. Gray

Direct Shear Testing  
Sidley # 2000 Sand

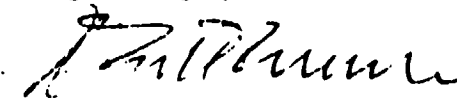
Gentlemen

I have enclosed two copies of:

- a. A summary of test results for Angles Of Internal Friction.
- b. Graphical presentation of Peak and Ultimate Shear data for #2000 sand in a loose condition.
- c. Graphical presentation of Peak and Ultimate Shear data for #2000 sand in a compact condition.

Please notify me if you need additional data from these tests, or additional testing.

Very truly yours

  
J. Fred Triggs, Jr., P.E.

encl:

JFTcd

J FRED TRIGGS, JR., P E  
5765 MAYFIELD ROAD  
CLEVELAND, OHIO 44124

CONSULTING ENGINEER

January 19, 1970

TEL 216 - 449-4418

General Motors Corporation  
Earthmoving Division  
Hudson, Ohio 44236

Internal Friction Angles From Direct Shear Testing

Loose Condition; Air Dry Density = 96.5 lb/cu. ft.

Normal Pressure	Peak Angle $\phi_m$	Ultimate Angle $\phi_u$
515 psf	39.0°	38.3°
919	35.2	34.4
1320	34.6	33.9
1760	34.6	34.6
2130	35.3	35.3
2560	33.4	33.0
Average	35.3°	34.9°

Compact Condition; Air Dry Density = 106.6 lb/cu. ft.

Normal Pressure	Peak Angle $\phi_m$	Ultimate Angle $\phi_u$
515 psf	43.0°	38.8°
919	42.3	35.0
1320	41.0	33.0
1760	39.5	32.7
2130	39.2	31.8
2560	40.3	31.7
Average	40.8°	33.8°

Soil: Sidley #2000 sand      Specimen thickness: 2.0 cm.  
Shear box diam: 2.5 in.      Shear rate: 0.12 in/min.

J. FRED TRIGGS JR., P.E.  
5765 MAYFIELD ROAD  
CLEVELAND, OHIO 44124

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Earthmoving Division  
Hudson, Ohio 44236

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1320	41.0	33.0
1760	39.5	32.7
2130	39.2	31.8
2560	40.3	31.7
Average	40.8°	33.8°

Soil: Sidley #2000 sand      Specimen thickness: 2.0 cm.  
Shear box diam: 2.5 in.      Shear rate: .012 in/min.

General Motors Corporation

Earthmoving Division

Peak Shear Angle =

35.3° Average

Ultimate Shear Angle = 34.9° Average

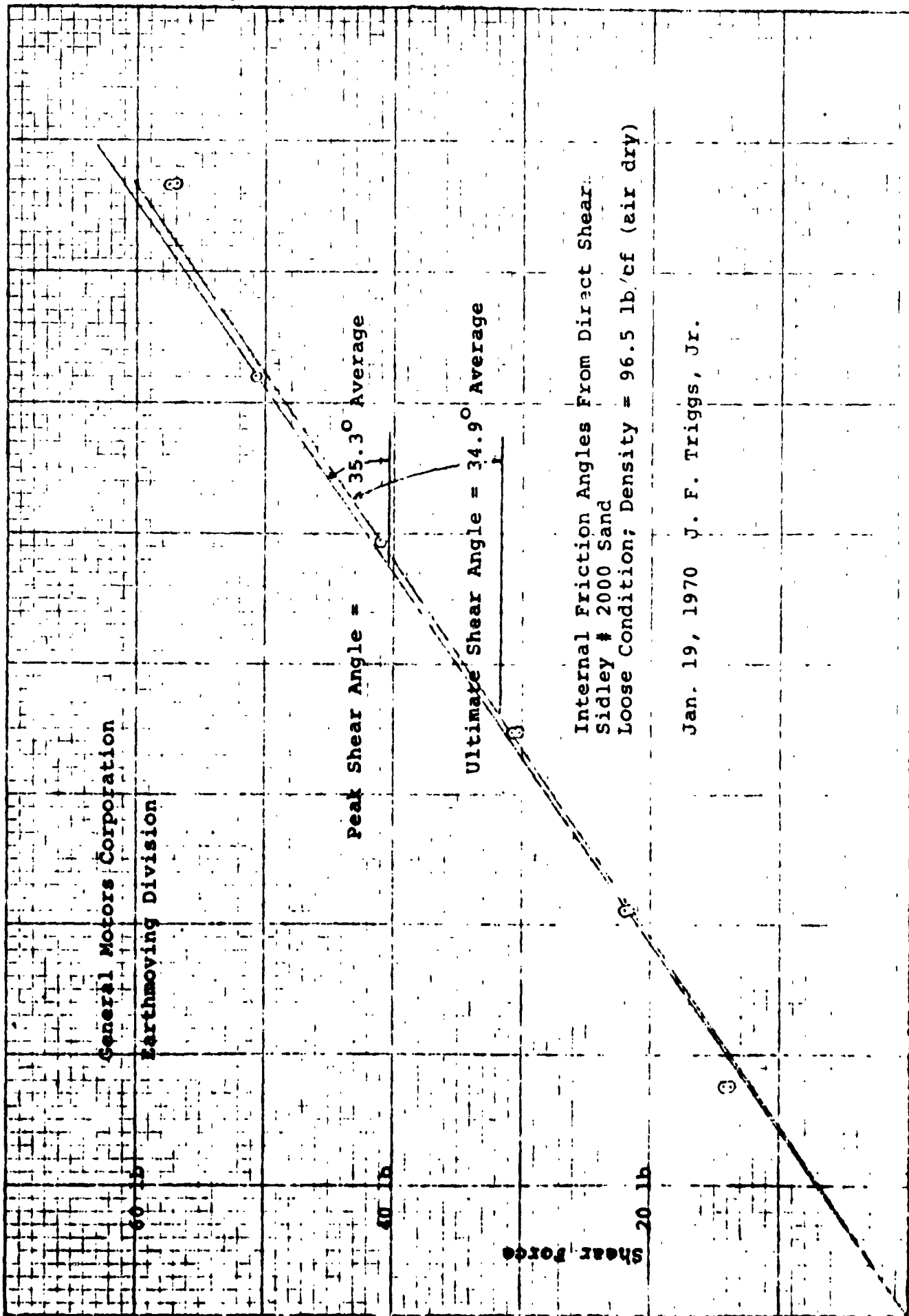
Internal Friction Angles From Direct Shear:  
Sidley # 2000 Sand  
Loose Condition; Density = 96.5 lb/cf (air dry)

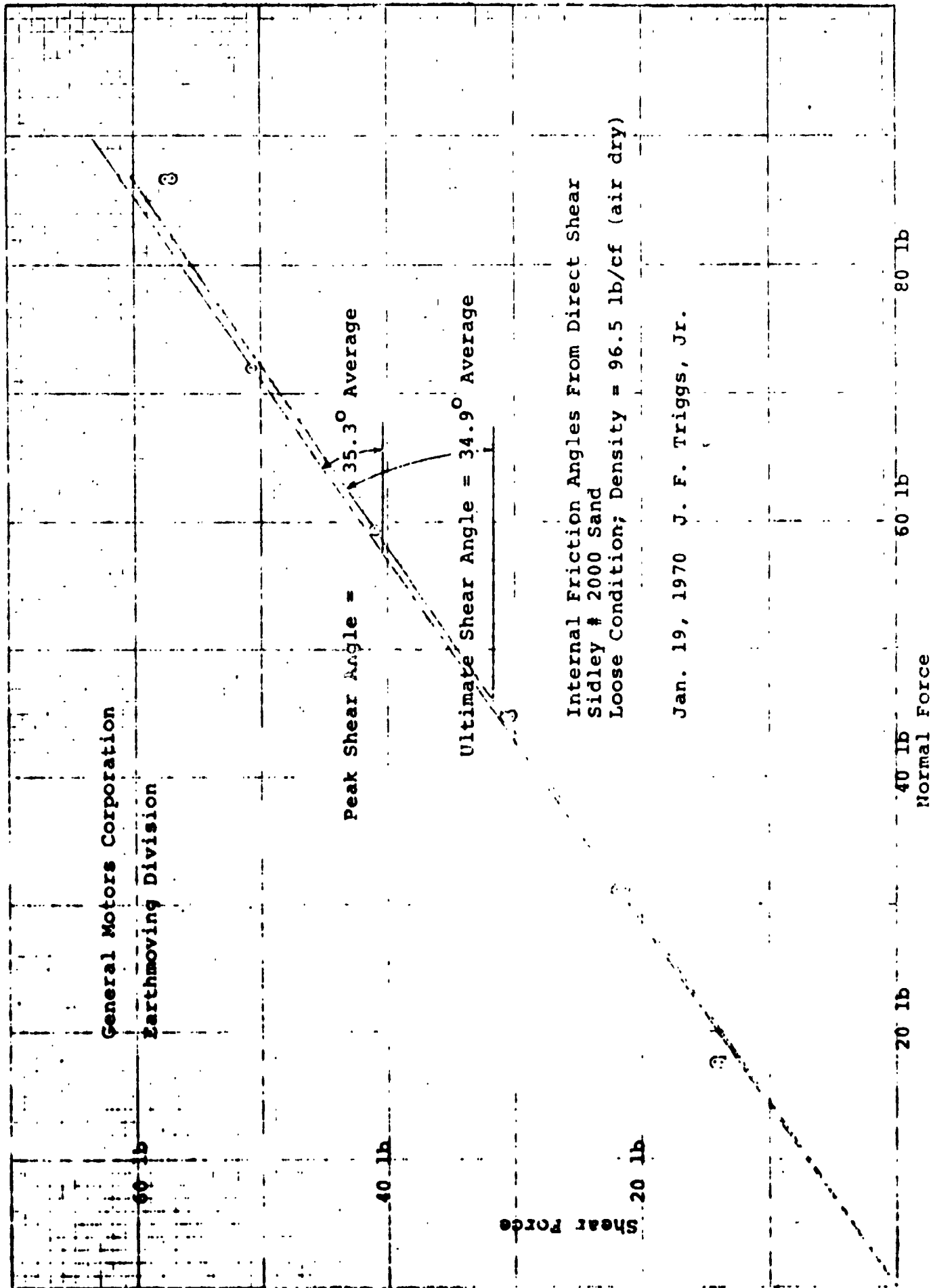
Jan. 19, 1970 J. F. Triggs, Jr.

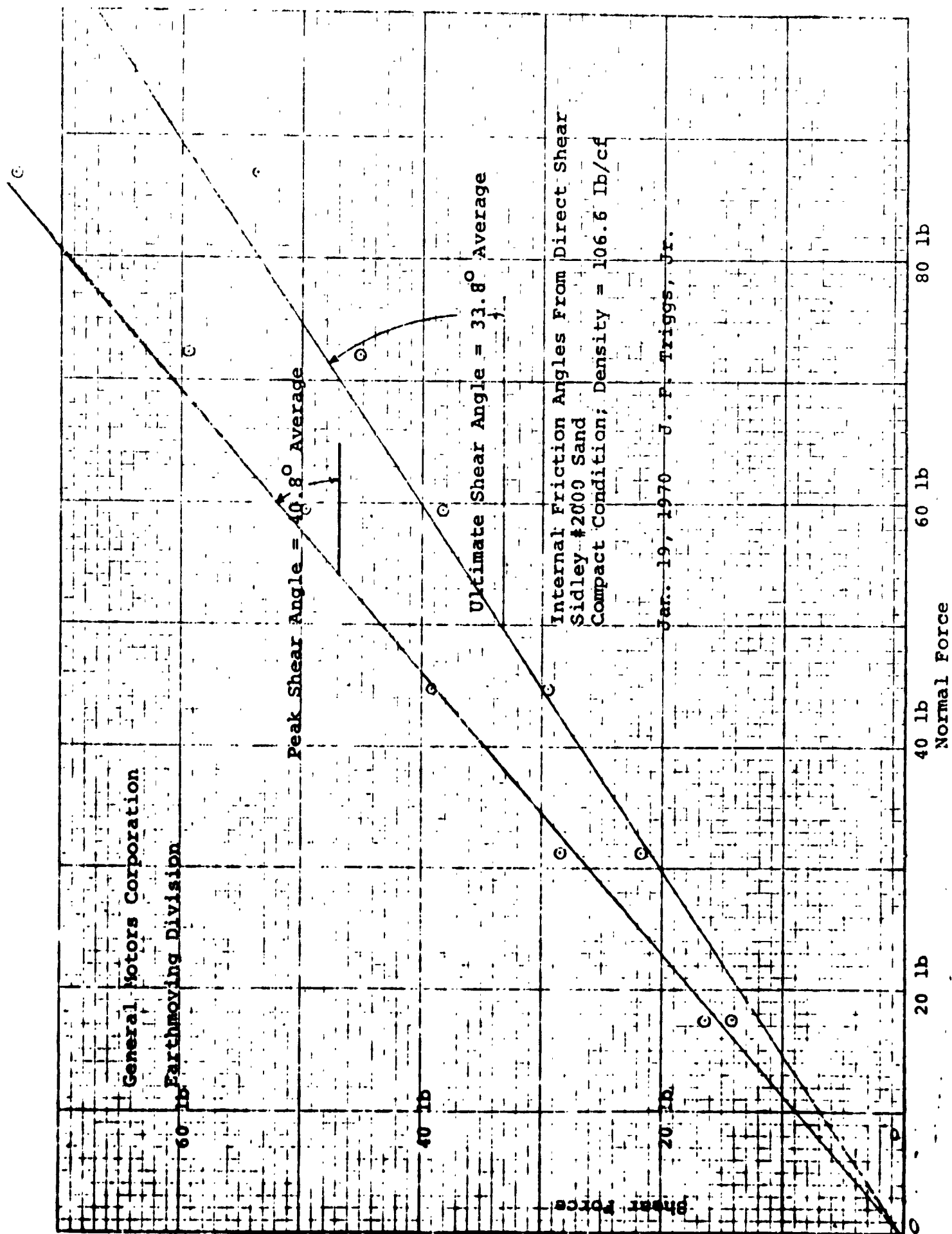
40 lb 60 lb 80 lb  
Normal Force

20 lb

Shear Force







General Motors Corporation

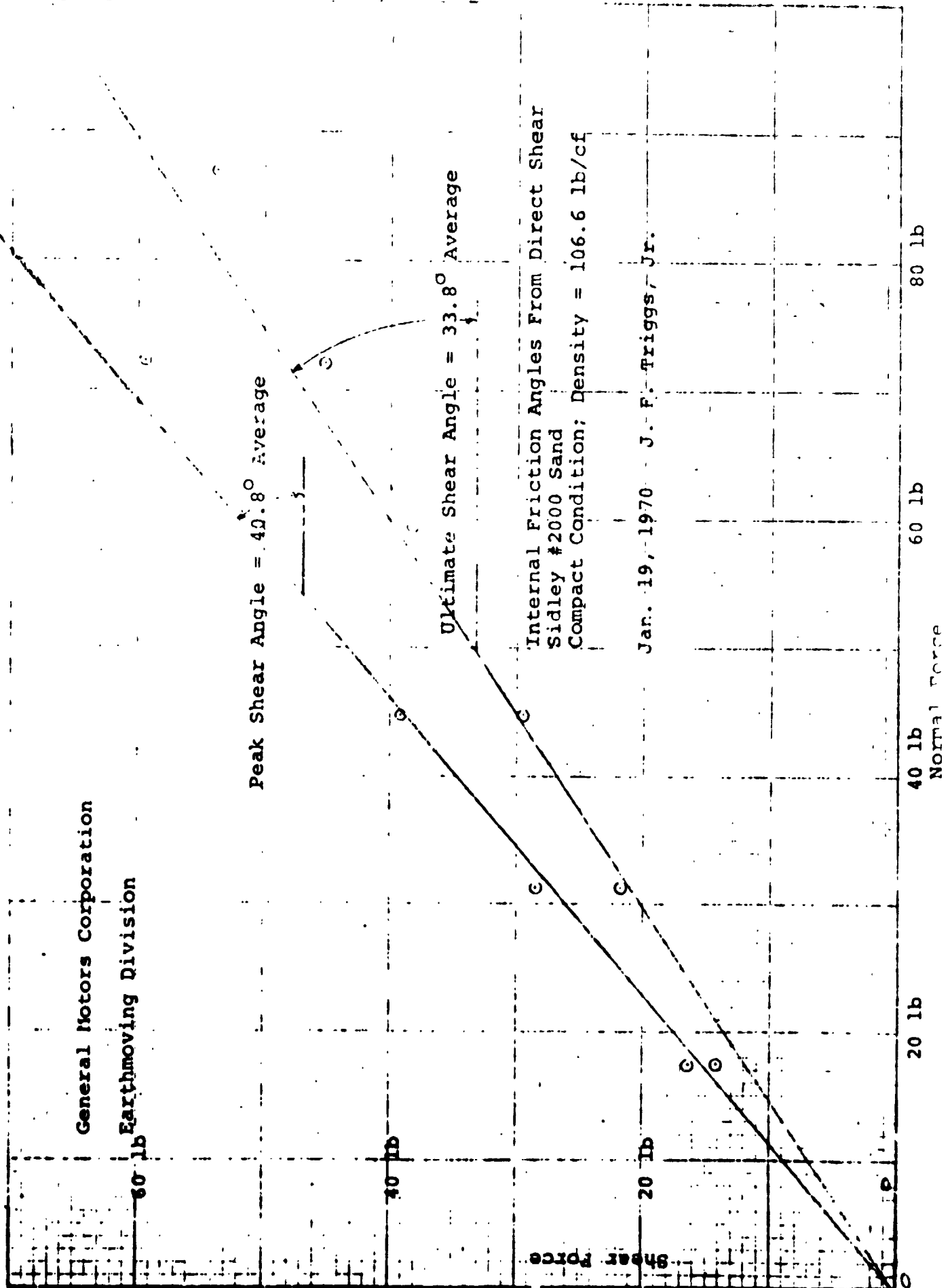
Earthmoving Division

Peak Shear Angle =  $40.8^\circ$  Average

Ultimate Shear Angle =  $33.8^\circ$  Average

Internal Friction Angles From Direct Shear  
Sidley #2000 Sand  
Compact Condition; Density = 106.6 lb/cf

Jan. 19, 1970 J. F. Triggs, Jr.

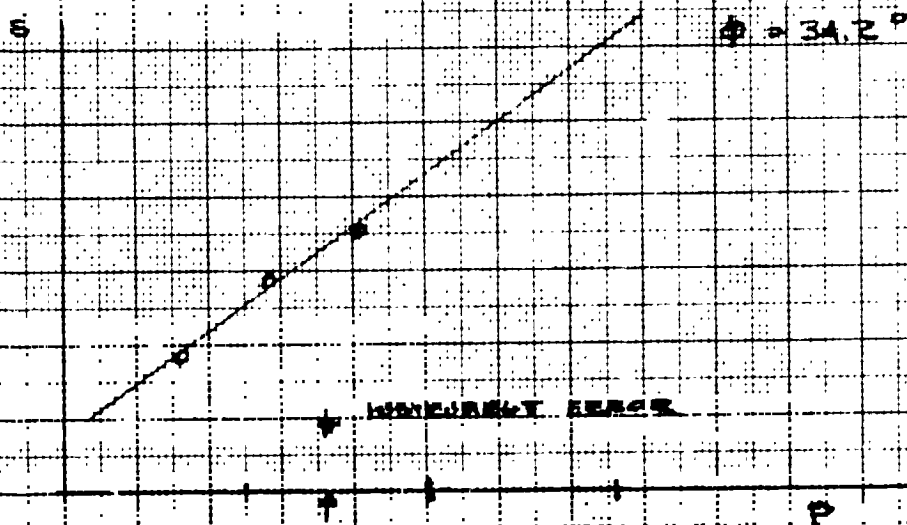




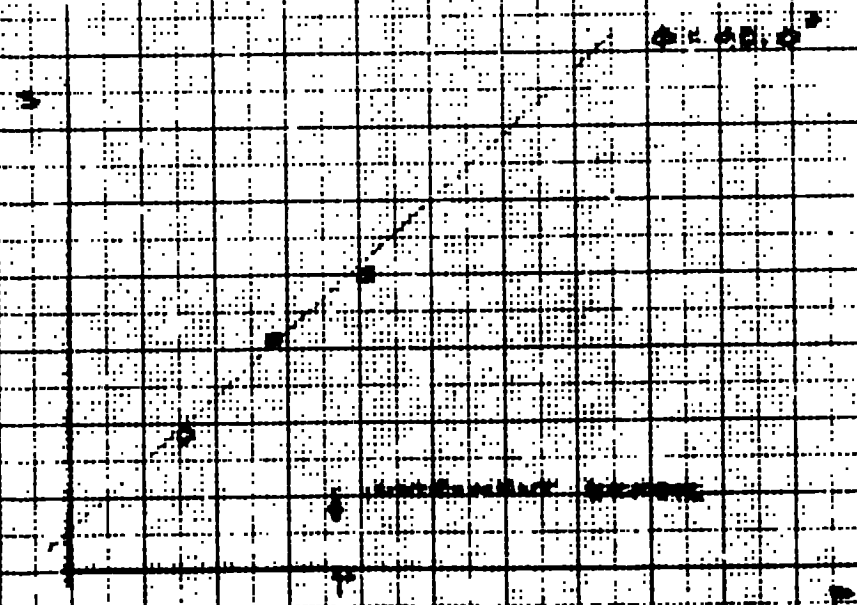
# SHEAR TESTS

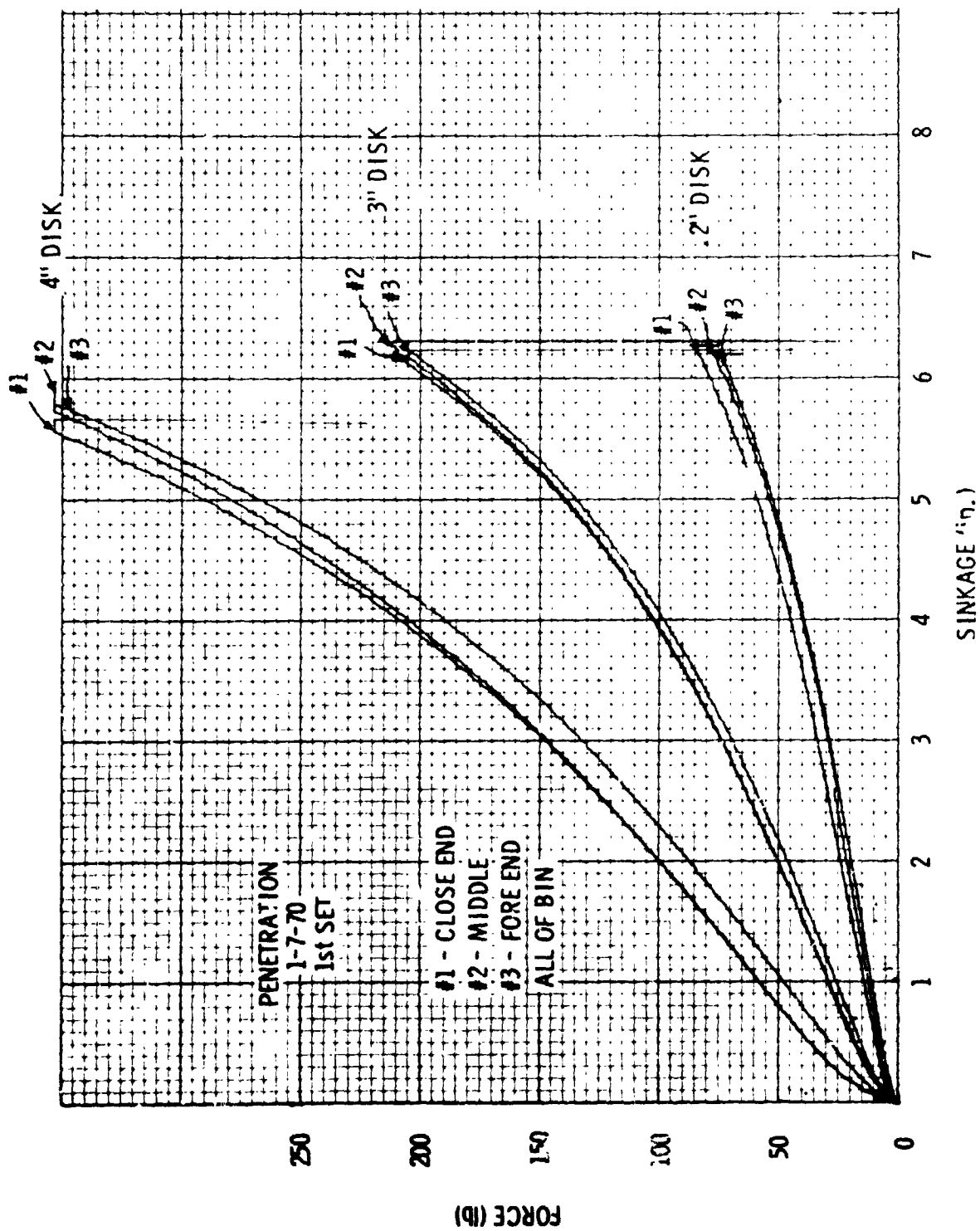
CRUSHED, SILICA SAND, AIR DRY

LOOSE SOIL AND ULTIMATE FOR COMPACTED SOIL

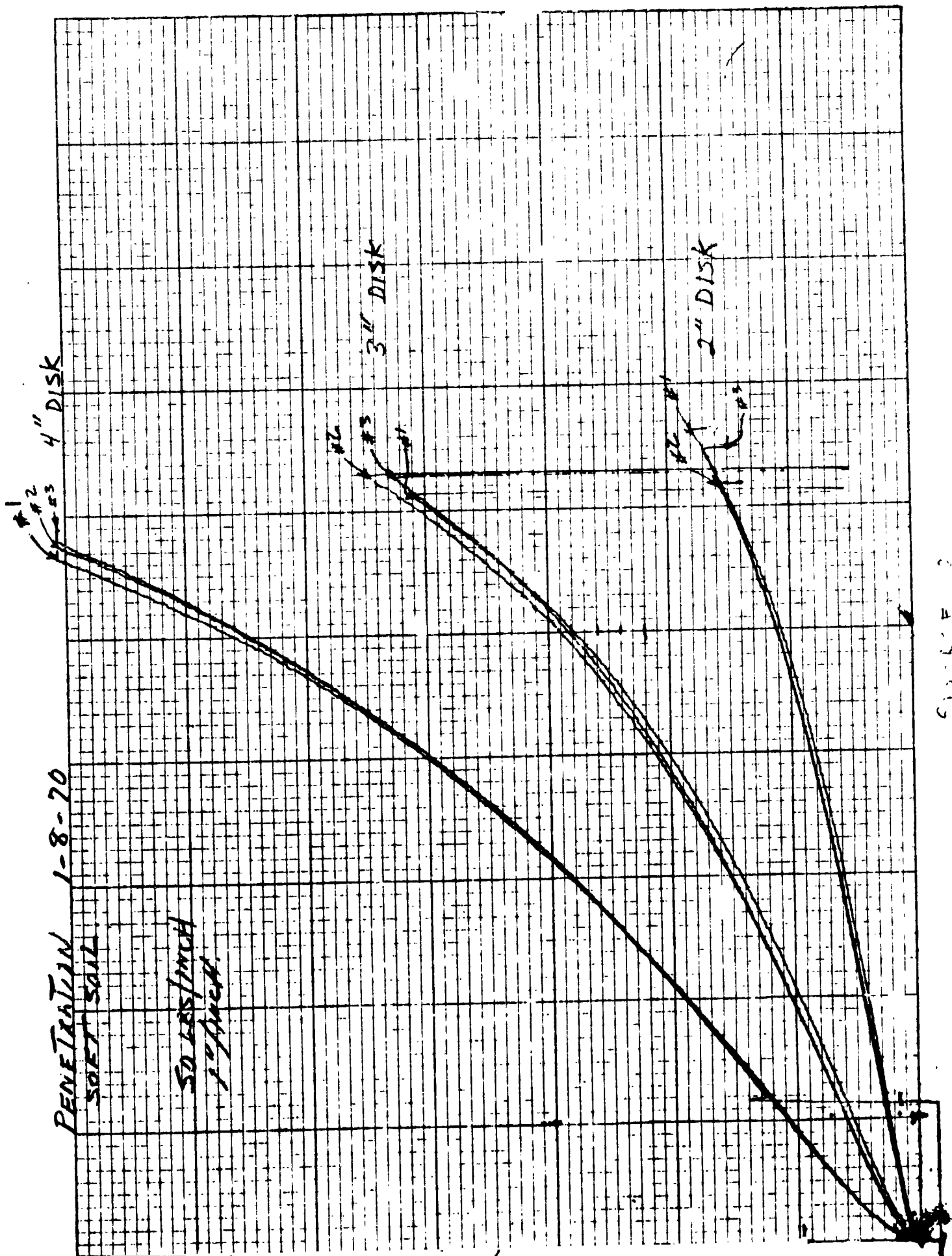


PEAR COMPACTED CONDITION





Example of Penetrometer Tests in Loose, Air Dry, Crushed Silica Sand



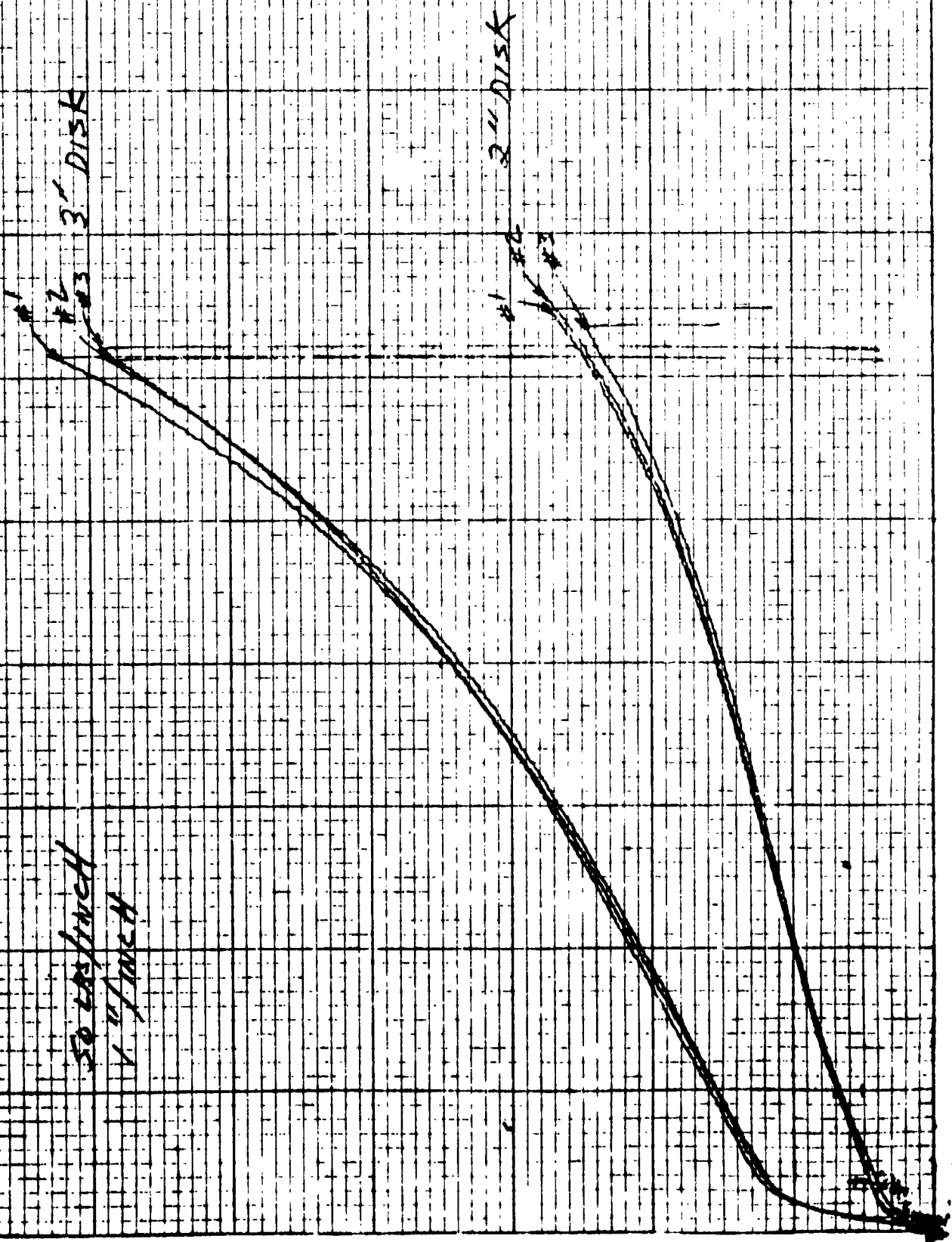
50-20-4

1-9-70

PENETRATION

PERCENT

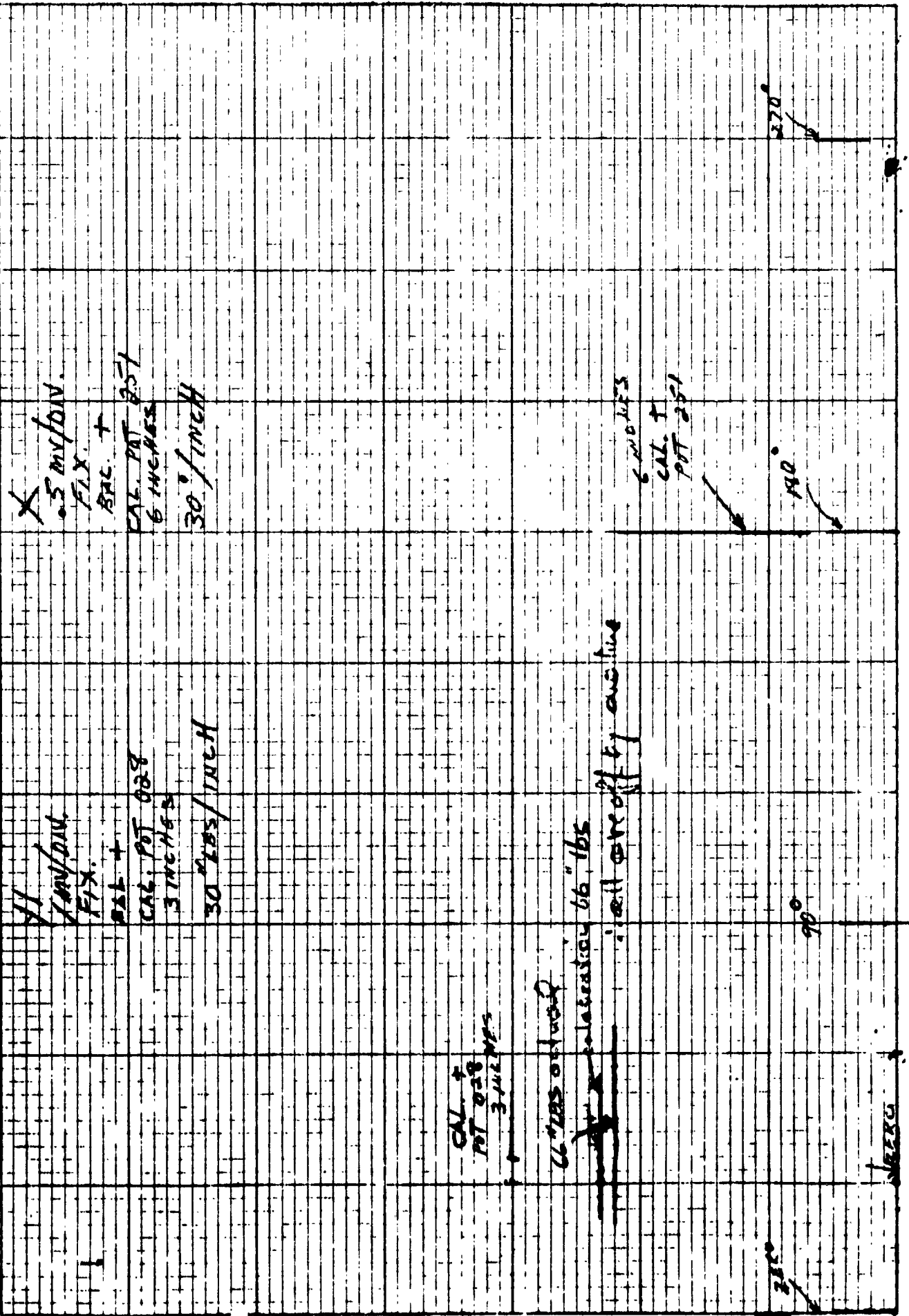
50 LB/INCH  
1 INCH



1-17

21

# SHEAR CALIBRATION 1-7-20



# C. ANALYSIS

LOOSE SOIL

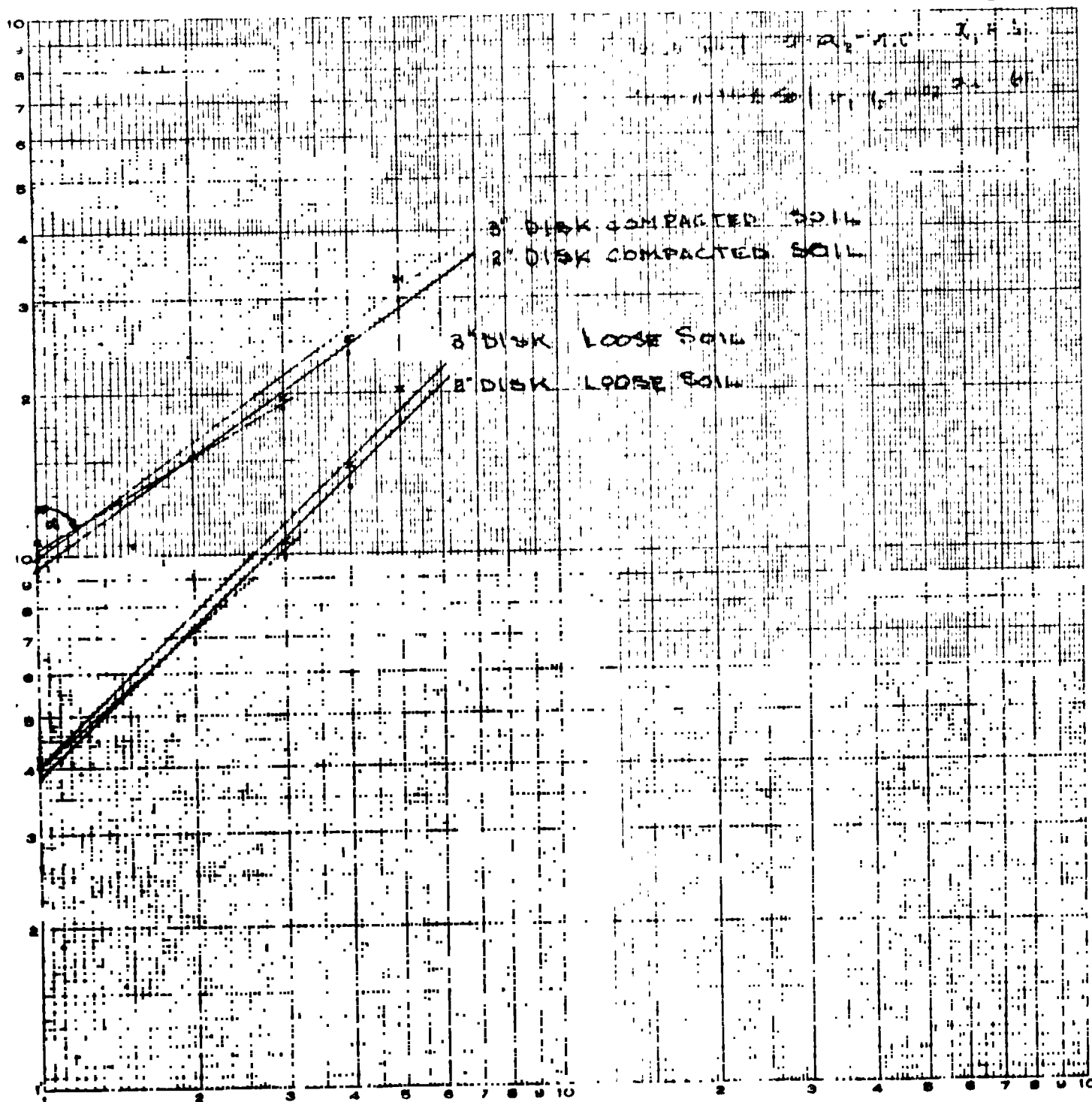
2" DISK  $a_1 = 3.81$   $\alpha_1 = 46.7^\circ$

3" DISK  $a_2 = 4.04$   $\alpha_2 = 46.6^\circ$

COMPACTED SOIL

2" DISK  $a_1 = 9.41$   $\alpha_1 = 55.5^\circ$

3" DISK  $a_2 = 9.90$   $\alpha_2 = 55.0^\circ$



↑  
Z

A.P. Victor 1-15-70

PAGE 1/9

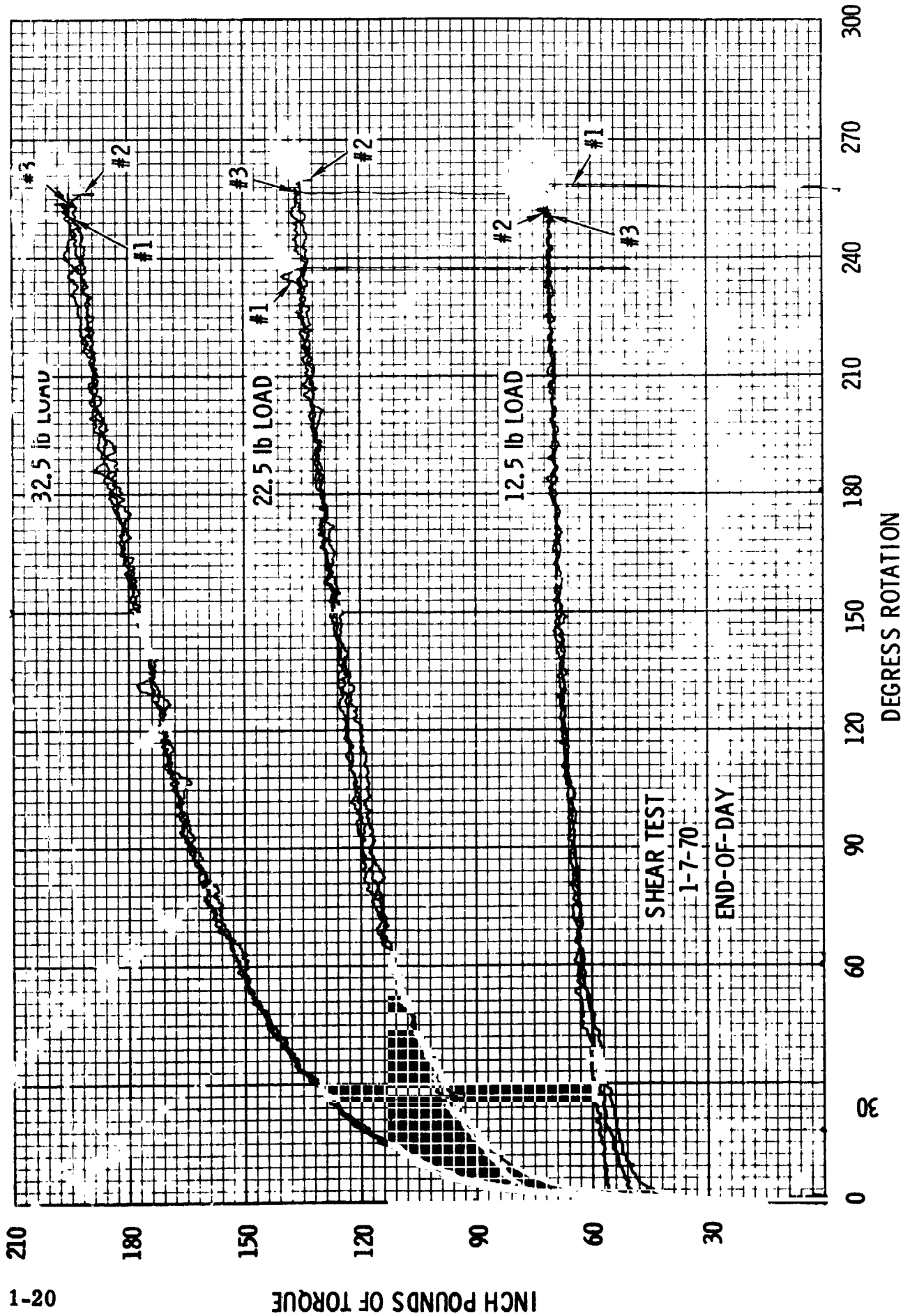


Figure 24 Examples of Shear Tests in Loose, Air Dry, Crushed Silica Sand

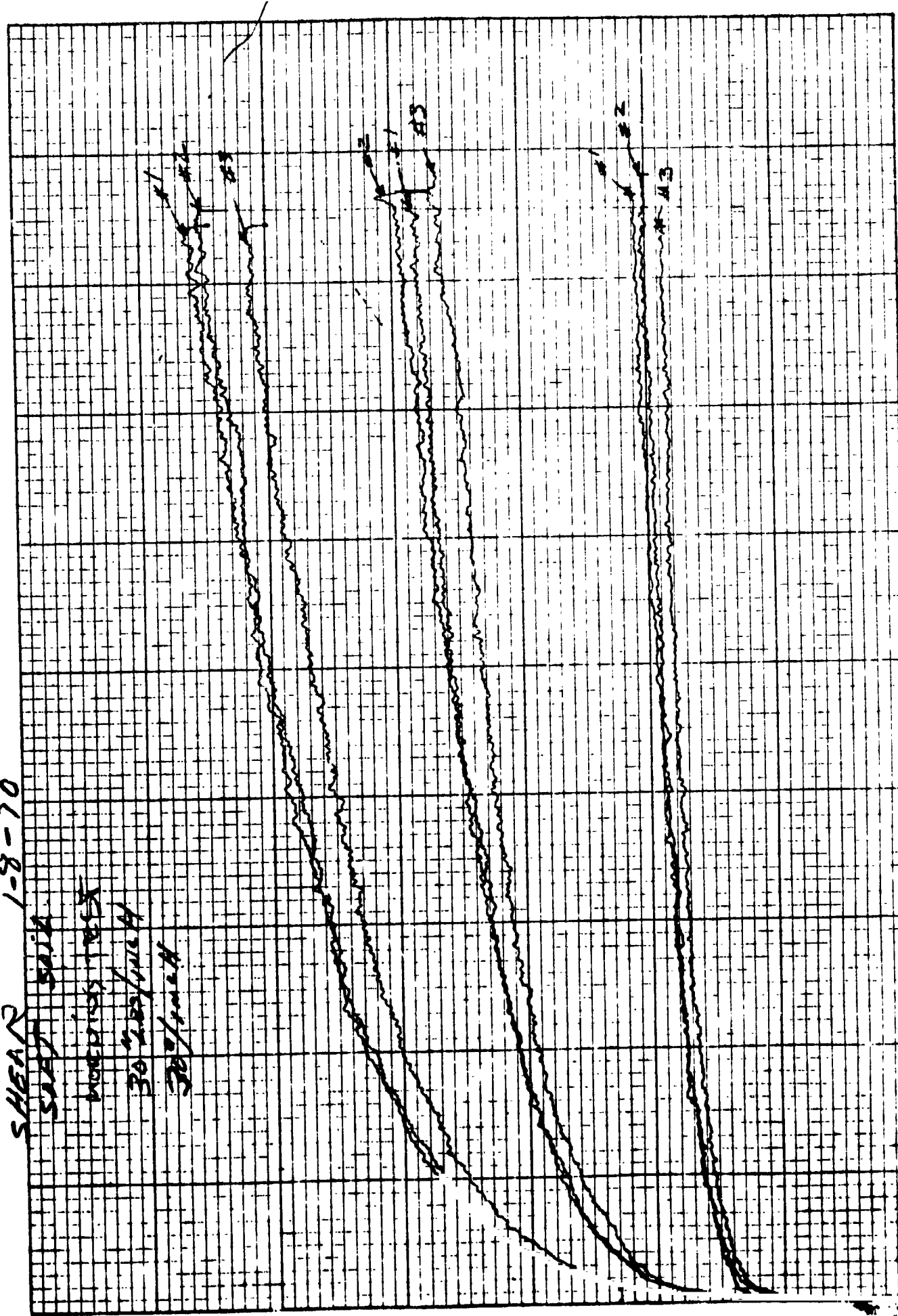
SHEAR 1-8-70

SHEAR DATA

BOREHOLE TEST

30" 2.00/INCH

30" 1.00/INCH





SHEAR 1-8-76

PACKED SOIL

30 WBS/INCH

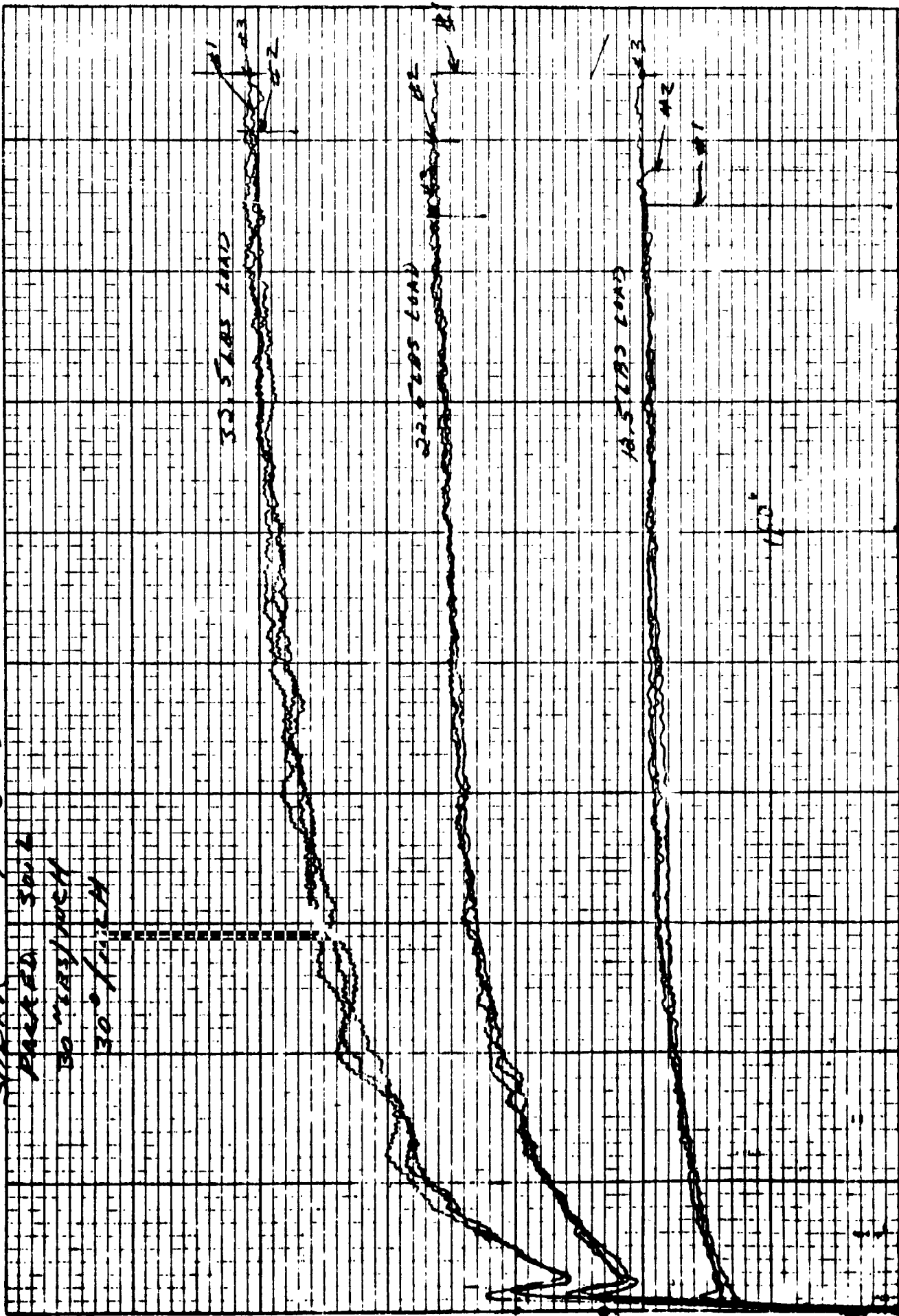
30°/INCH

32.5 LBS LOAD

22.5 LBS LOAD

18.5 LBS LOAD

100°



SHEAR 1-9-20

MAX TO MIN

30" 205/INCH

30" 9/INCH

32.5" 485 LORI #3

32.5" 485 LORI #3

12.5" 205 LORI #2

# PENETRATION CALIBRATION 1-7-70

X  
1. V/DIV.  
FIX.  
BAL. -

CAL. + 5 INCHES  
POT. = 070  
100/IN

11  
1. V/DIV.  
FIX.  
BAL. -

CAL. #1  
POT. 013  
50 LBS/IN

5 INCHES

CAL. #5  
POT. 070

5 INCHES  
POT. 013

5 INCHES

5 INCHES  
POT. 013

5 INCHES

DATE

1-8-70

EQUIP. TYPE LUNAR WHEEL  
Model  
Sr. No.  
Capacity

TESTED WITH SOIL BION  
Equip. type  
Model  
Sr. No.  
Capacity

TYPE CONNECTION  
Cable No.

THIS PAGE IS  
OF POOR QUALITY

RECORDER SANBORN  
Type 350  
Model  
Sr. No. N-22346  
Channel #4  
Type Plug-in DC. PRE-AMP  
Model 350-1300  
Sr. No. N-22278

CARRIER  
350-11000  
N-22273

CALIBRATION  
Gage Factor  
Zero Suppression in  
Zero Suppression Setting  
Attenuator scale X 5  
Zero Position CENTER  
Gain Setting 20.0 mm LEFT

500  
OUT  
0  
X 10  
CENTER  
20.0 mm LEFT

TEST SETTINGS  
Attenuator Scale X 5  
Zero Position CENTER  
Paper Speed 5 mm/sec  
Scale Factor 25.0 mm/cm

X 1  
CENTER  
5 mm/sec.  
25.0 mm/cm

TEST HORIZONTAL  
(FULL)

SIGNATURE

R. Bell

DATE 1-7-70

EQUIP. TYPE LUNAR WHEEL  
Model  
Sr. No.  
Capacity

TESTED WITH SOIL BIN  
Equip. type  
Model  
Sr. No.  
Capacity

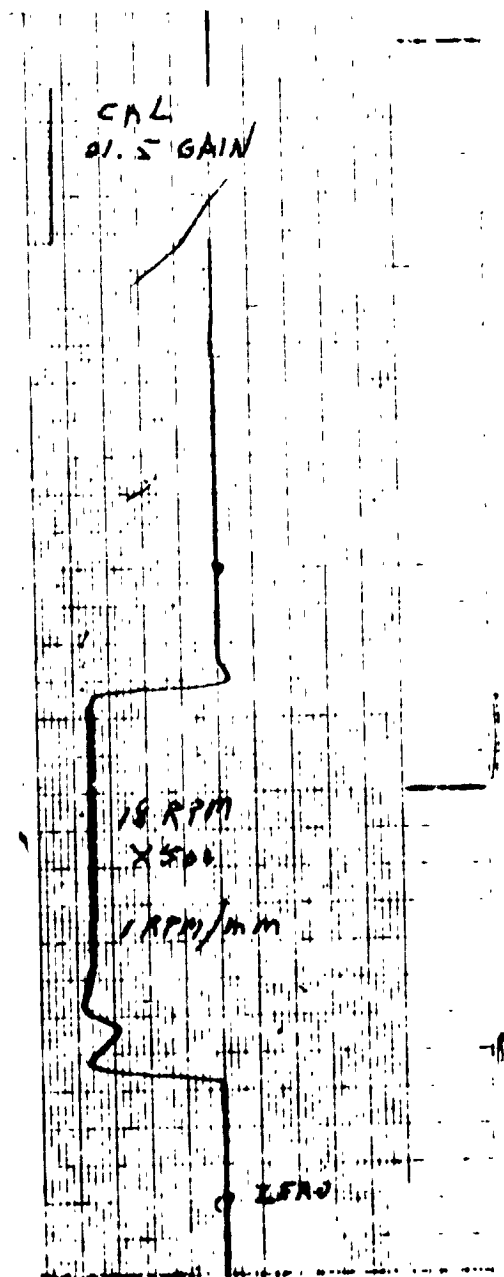
TYPE CONNECTION  
Cable No.

RECORDER SANBORN  
Type 350  
Model  
Sr. No. N-22346  
Channel #1  
Type Plug-in D.C. PRE-AMP.  
Model 350-1300  
Sr. No. N-22281

CALIBRATION  
Gage Factor —  
Zero Suppression in out  
Zero Suppression Setting 0  
Attenuator scale X 500  
Zero Position CENTER  
Gain Setting 21.5 AM LEFT

TEST SETTINGS  
Attenuator Scale X 500  
Zero Position CENTER  
Paper Speed 5 mm/sec.  
Scale Factor 10 RPM/cm.

TEST WHEEL SPEED



SIGNATURE R. Bell

DATE 1-7-70

EQUIP. TYPE LUNDT WHEEL  
Model  
Sr. No.  
Capacity

TESTED WITH SOIL BIN  
Equip. type  
Model  
Sr. No.  
Capacity

ORIGINAL PAGE IS  
OF POOR QUALITY

TYPE CONNECTION  
Cable No.

RECORDER SANBORN  
Type 350  
Model  
Pr. No. N-22346  
Channel # 2  
Type Plug-in DC. PRE-AMP  
Model 750-1300  
Sr. No. N-22280

CALIBRATION  
Gage Factor  
Zero Suppression in out  
Zero Suppression Setting  
Attenuator scale X1000.  
Zero Position 1 cm FROM RIGHT EDGE  
Gain Setting 26.0 mm LEFT

TEST SETTINGS  
Attenuator Scale X1000  
Zero Position 1 cm FROM LEFT EDGE  
Paper Speed 5 in/sec.  
Scale Factor 1 in/sec/cm.

TEST CARRIAGE SPEED

SIGNATURE

R. Bell

DATE

1-7-70

EQUIP. TYPE LUNAR WHEEL  
Model  
Sr. No.  
Capacity

TESTED WITH SOIL BIN  
Equip. type  
Model  
Sr. No.  
Capacity

TYPE CONNECTION  
Cable No.

RECORDER SANBORN  
Type  
Model 350  
Sr. No. N-22346  
Channel # 3  
Type Plug-in CARRIER  
Model 351-11008  
Sr. No. N-22277

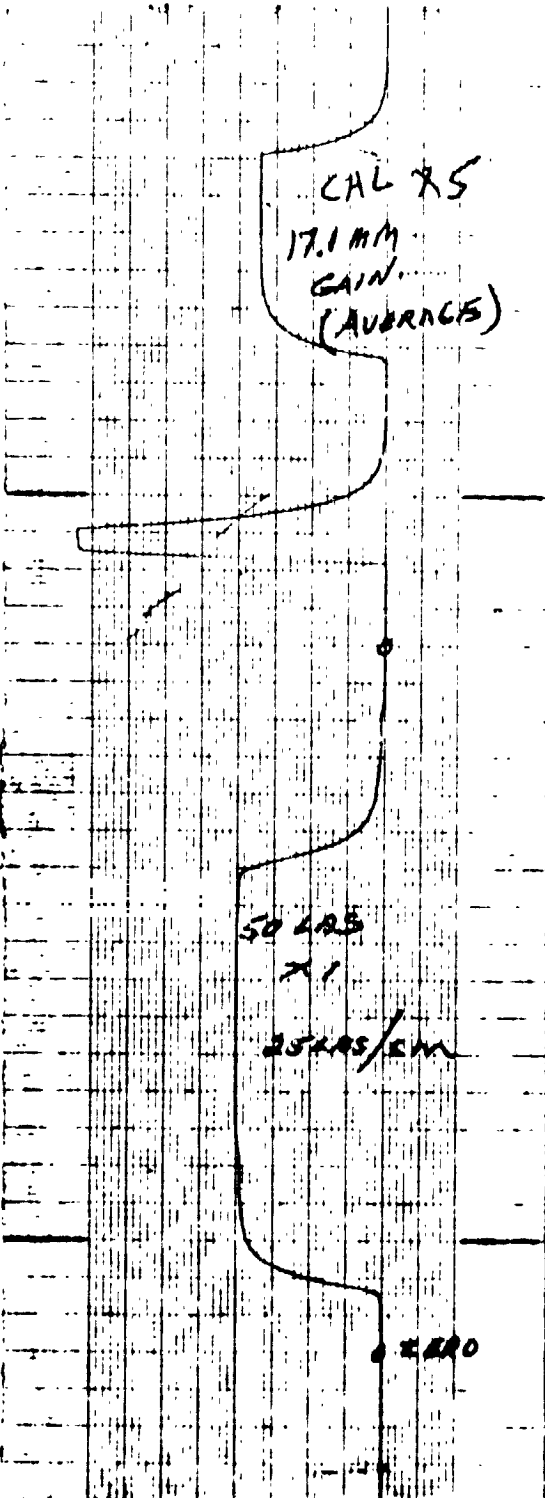
CALIBRATION  
Gage Factor 500  
Zero Suppression in out  
Zero Suppression Setting 0  
Attenuator scale X 5  
Zero Position 1 cm FROM RIGHT EDGE  
Gain Setting 17.1 mm LEFT

TEST SETTINGS  
Attenuator Scale X 1  
Zero Position 1 cm FROM RIGHT EDGE  
Paper Speed 5 mm/sec.  
Scale Factor 25 LBS/cm

TEST VERTICAL LOAD

SIGNATURE

R. Ball



DATE

1-7-70

EQUIP. TYPE

LUNAR WHEEL

Model

Sr. No.

Capacity

TESTED WITH

SOIL BIN

Equip. type

Model

Sr. No.

Capacity

TYPE CONNECTION

Cable No.

RECORDER

SANBORN

Type

350

Model

Sr. No. N-22346

Channel

#4

Type Plug-in DC

Model 350-1300

Sr. No. N-22278

CARRIER  
350-110013

N-22274

CALIBRATION

Gain Factor 500

Zero Suppression in

010

Zero Suppression Setting 0

Attenuator scale DC 5

CARRIER = X10

Zero Position

CENTER

Gain Setting 20mm LEFT

20.4mm LEFT

(AVERAGE)

TEST SETTINGS

DC

CARRIER

Attenuator Scale X5

X1

Zero Position

CENTER

Paper Speed 5mm

5 mm/sec.

Scale Factor .5VILTS =

1cm

25LBS/cm.

TEST

HORIZONTAL  
(PULL)

SIGNATURE

R. Bell



DATE

1-7-10

EQUIP. TYPE

LUNAR WHEEL

Model

Sr. No.

Capacity

TESTED WITH

SOIL BIN

Equip. type

Model

Sr. No.

Capacity

TYPE CONNECTION

Cable No.

RECORDER

SANBORN

Type

350

Model

Sr. No. N-22346

Channel

#5

Type Plug-in

CARRIER

Model

350-1100B

Sr. No.

N-22261

CALIBRATION

Gage Factor 500

Zero Suppression in

OUT

Zero Suppression Setting

0

Attenuator scale

X2

Zero Position RIGHT EDGE OF TRACE

Gain Setting 39.2 mm LEFT

TEST SETTINGS

Attenuator Scale

X2

Zero Position RIGHT EDGE

Paper Speed

5 mm/sec.

Scale Factor 100 lbs/cm

TEST TORQUE

SIGNATURE

R. Bell

CAL X2  
29.2 mm  
GAIN

300 lbs  
X5  
50 lbs/cm

600 lbs  
X5  
50 lbs/cm

300 lbs  
X2  
100 lbs/cm

ZERO

DATE

70

EQUIP. TYPE *WARR WHEEL*  
Model  
Sr. No.  
Capacity

TESTED WITH *WIL BIN*  
Equip. type  
Model  
Sr. No.  
Capacity

TYPE CONNECTION  
Cable No.

RECORDER *SANBORN*  
Type  
Model  
Sr. No. *100-1000*  
Channel *6*  
Type Plug-in *D.C. PRE-AMP.*  
Model *100-1000*  
Sr. No. *100-1000*

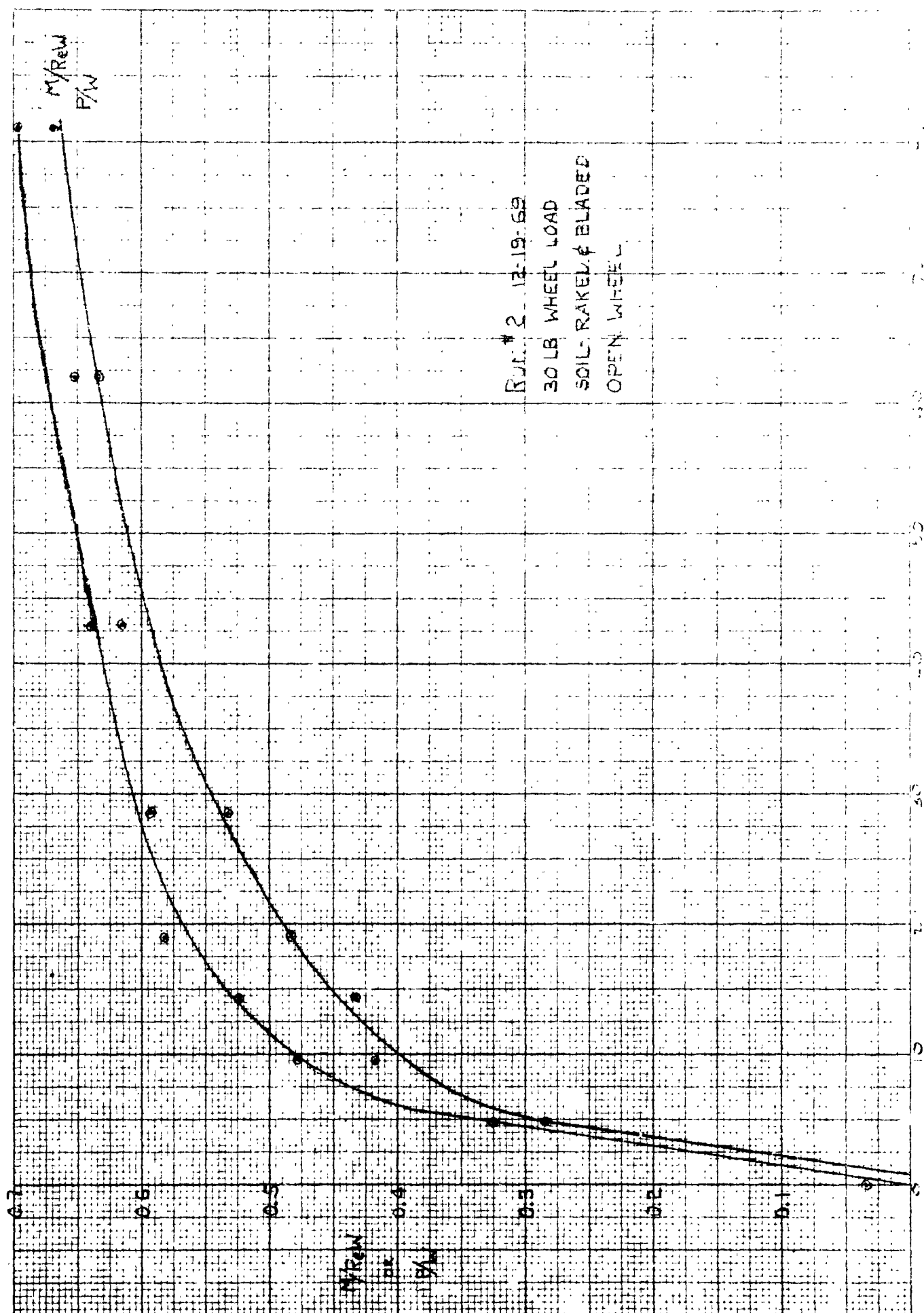
CALIBRATION  
Gain Factor  
Zero Suppression in *(out)*  
Zero Suppression Setting *0*  
Attenuator scale *X 1*  
Zero Position *1 cm FROM RIGHT EDGE*  
Gain Setting *18.1 mm LEFT*

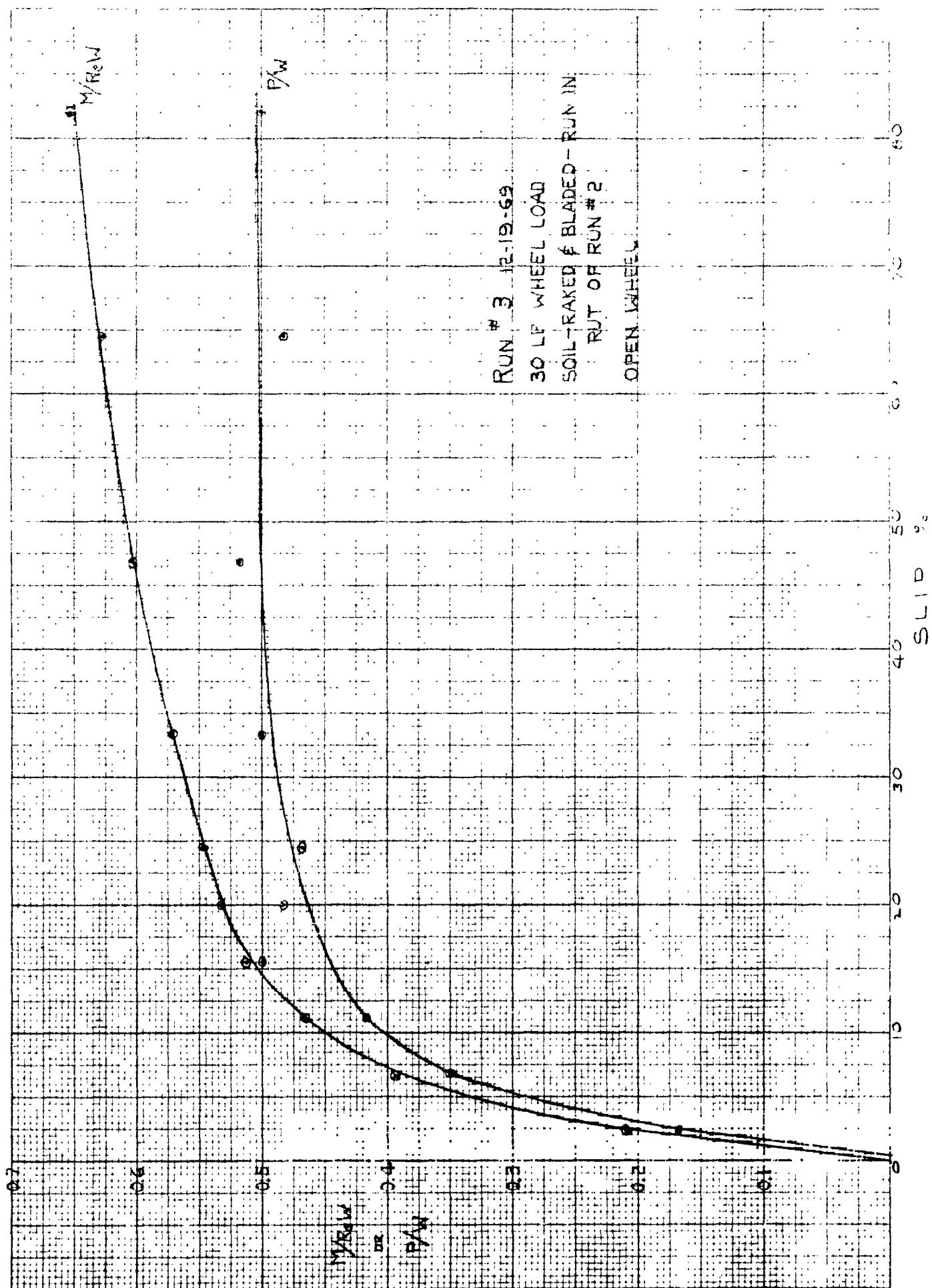
TEST SETTINGS *X 1*  
Attenuator Scale  
Zero Position *1 cm FROM RIGHT EDGE*  
Paper Speed *5 mm/sec.*  
Scale Factor *2 1/2 cm*

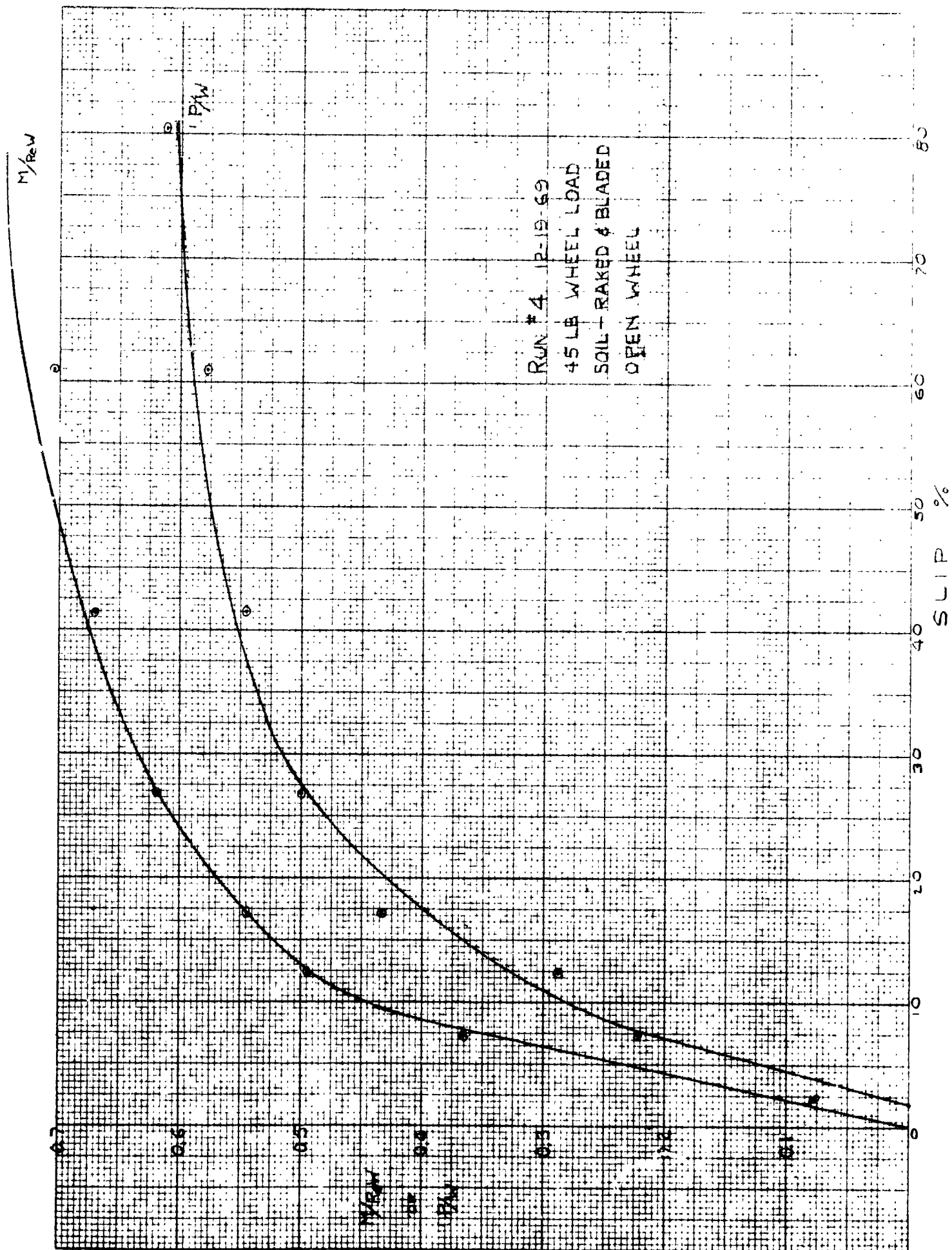
TEST SINKAGE

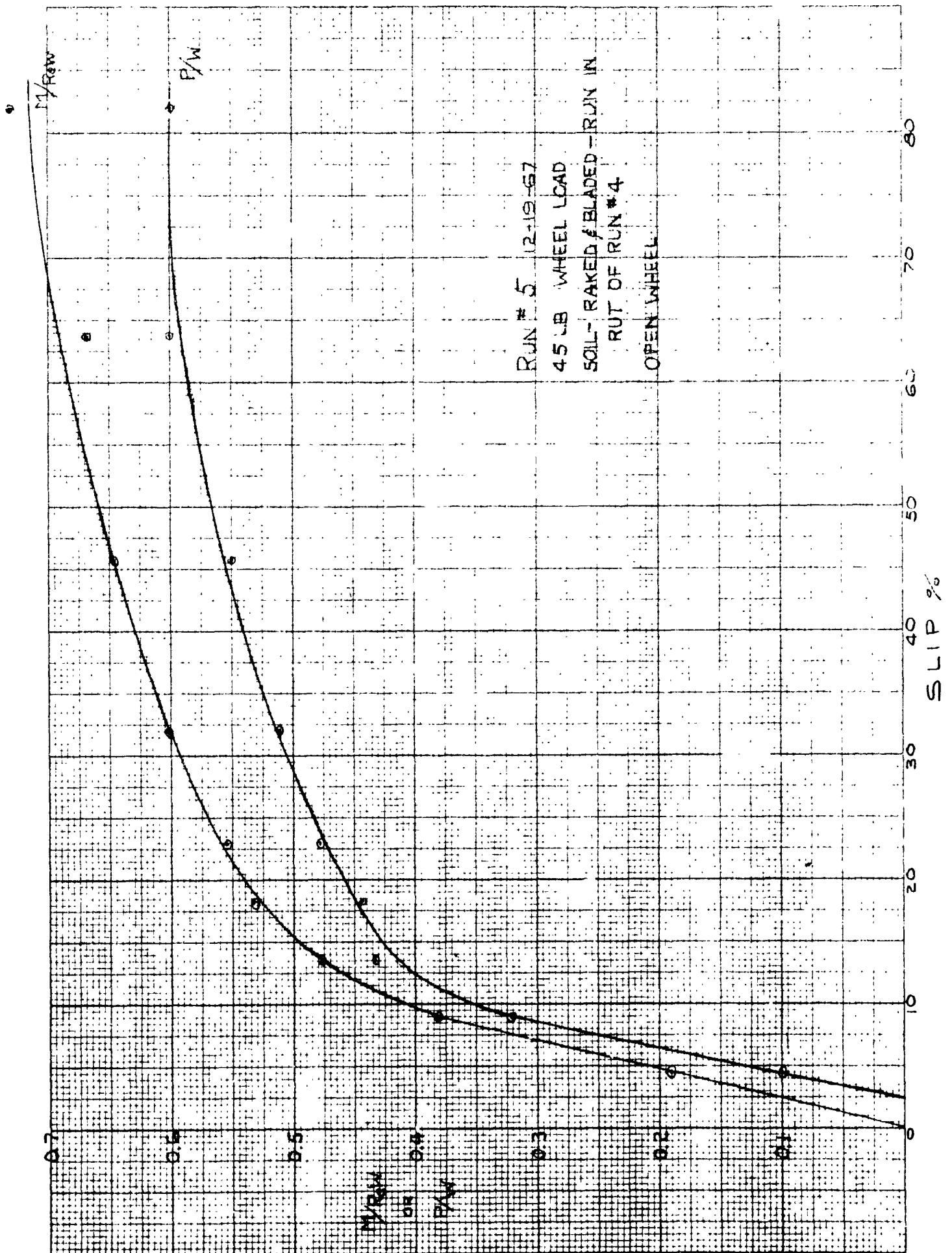
SIGNATURE

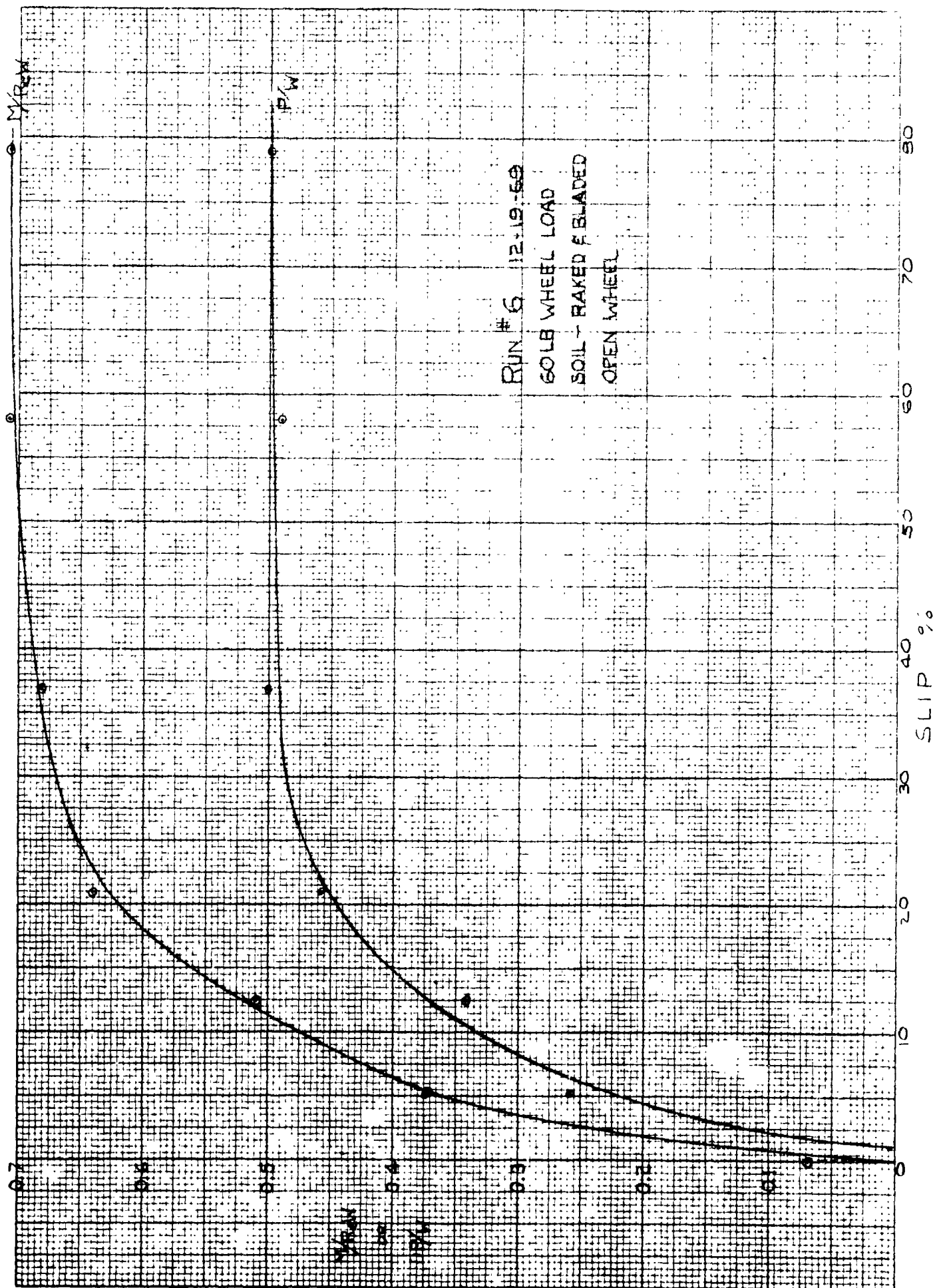
*R. Bell*



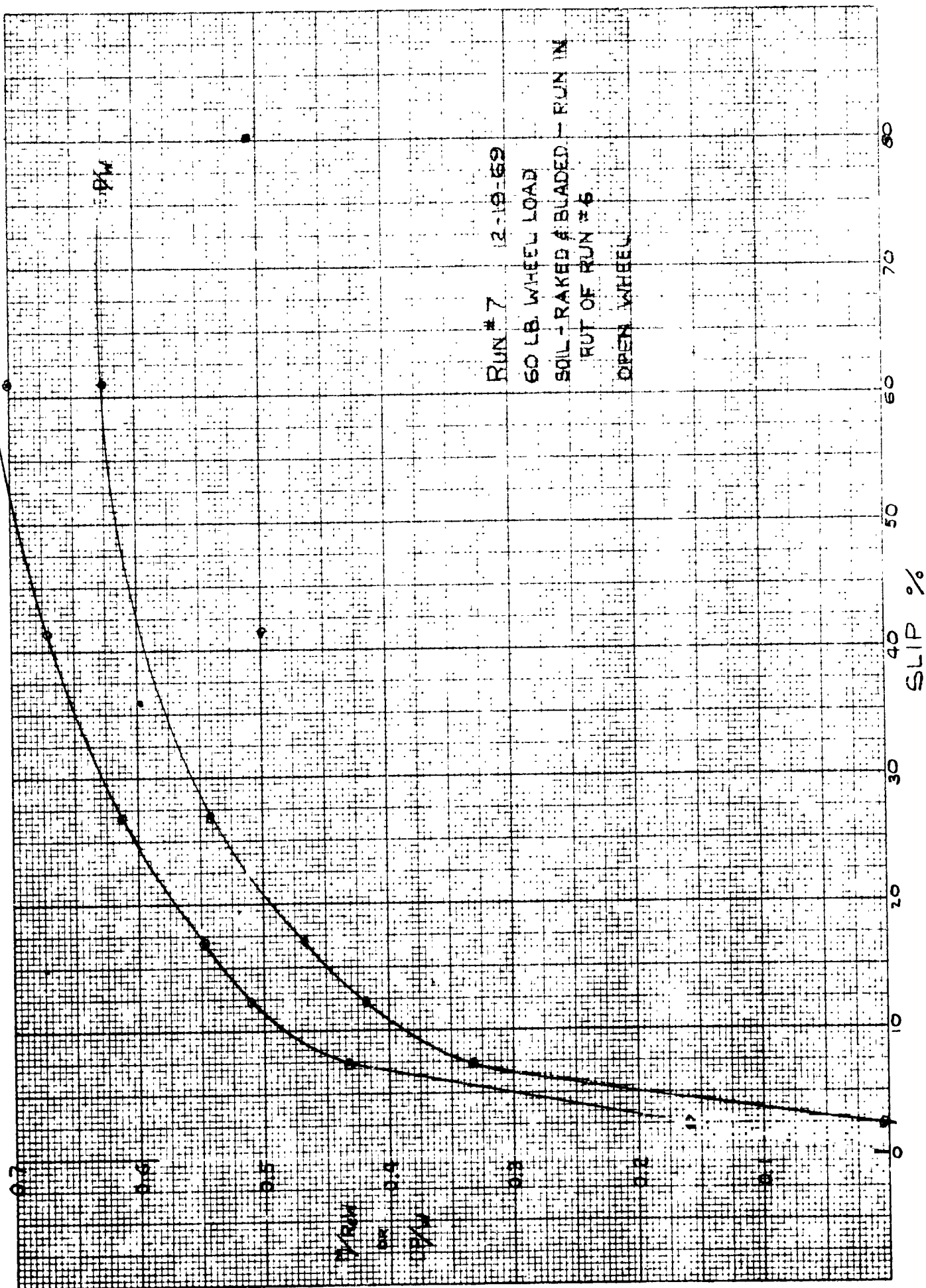




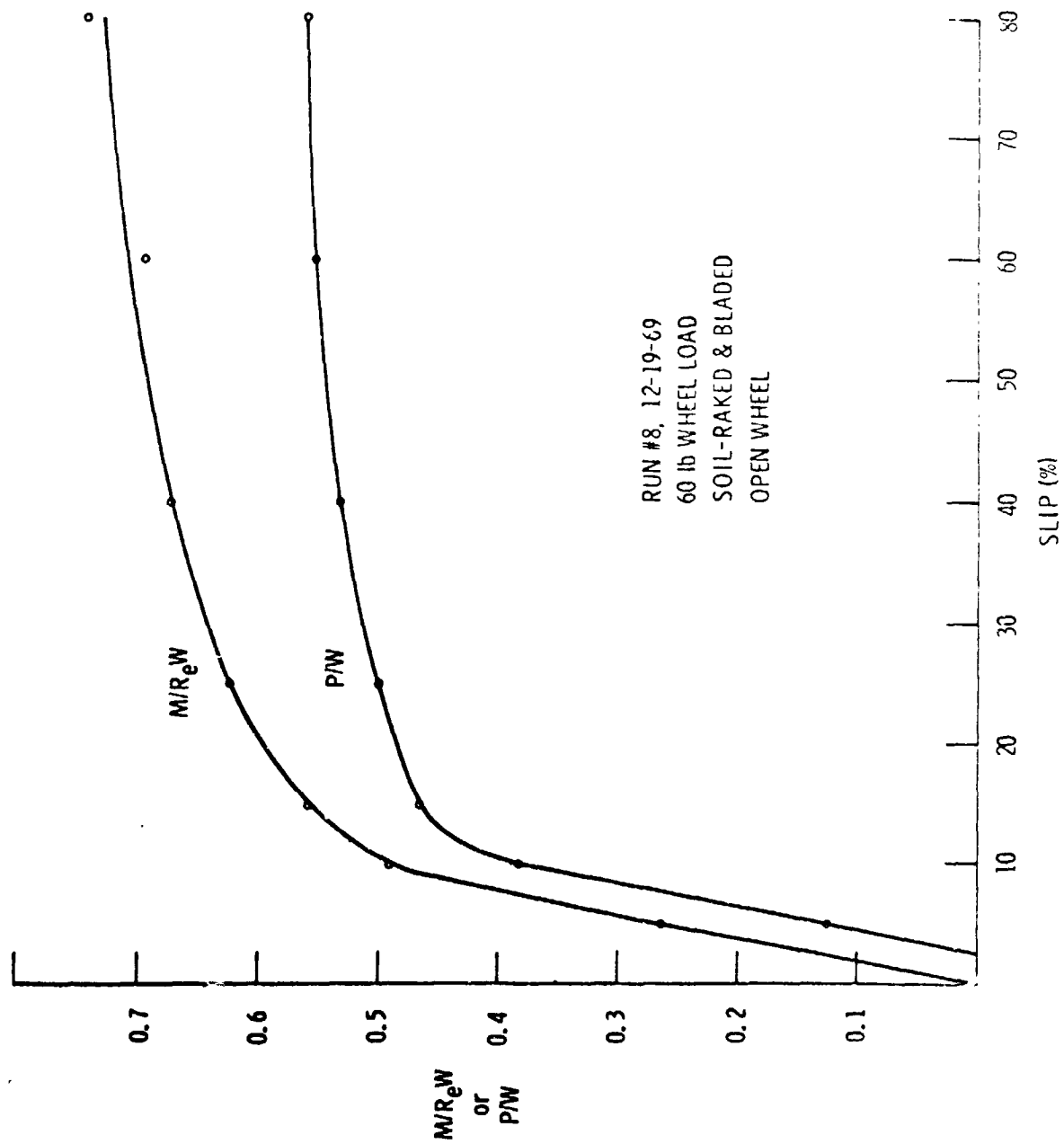




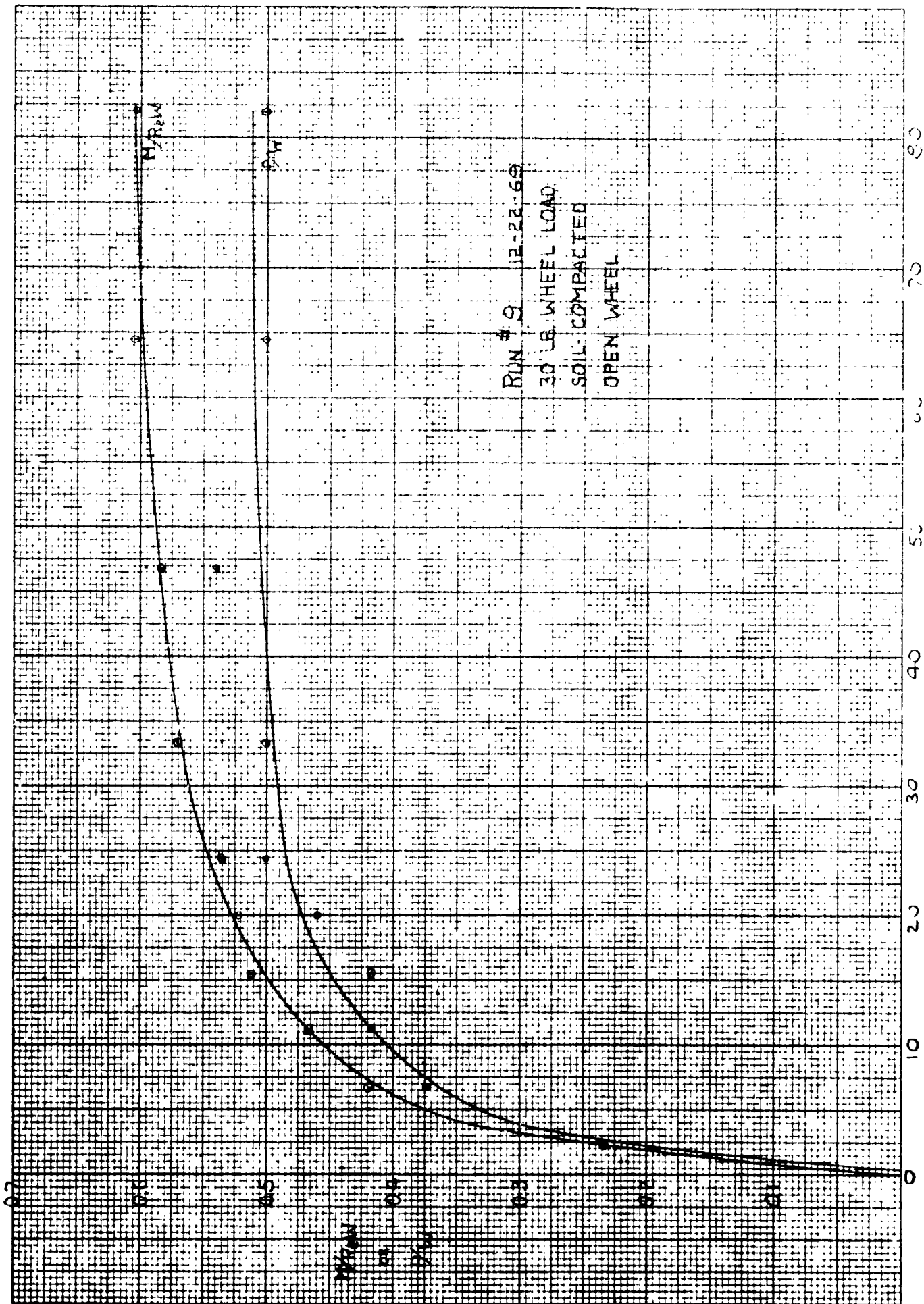
$M/R_o W$

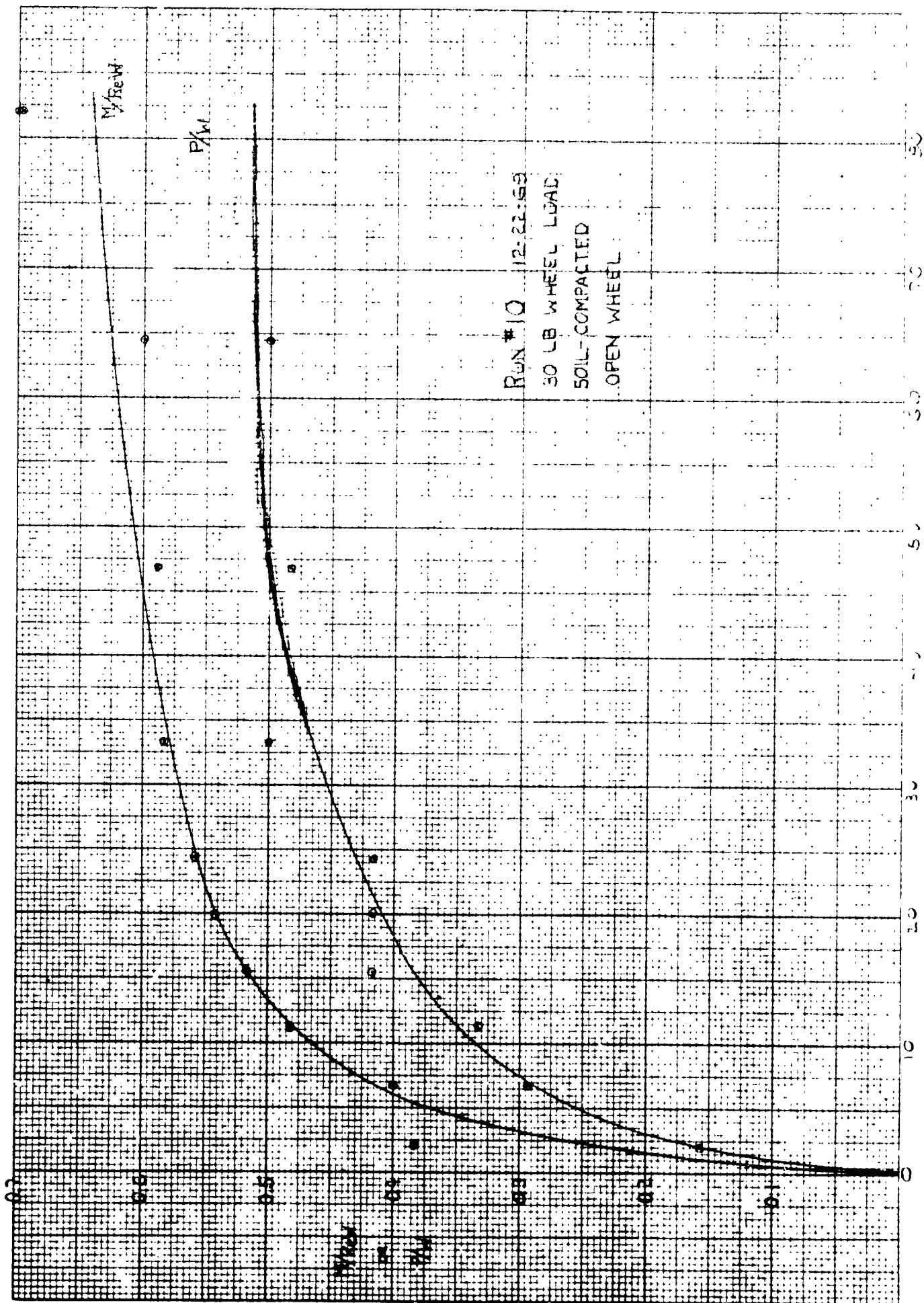


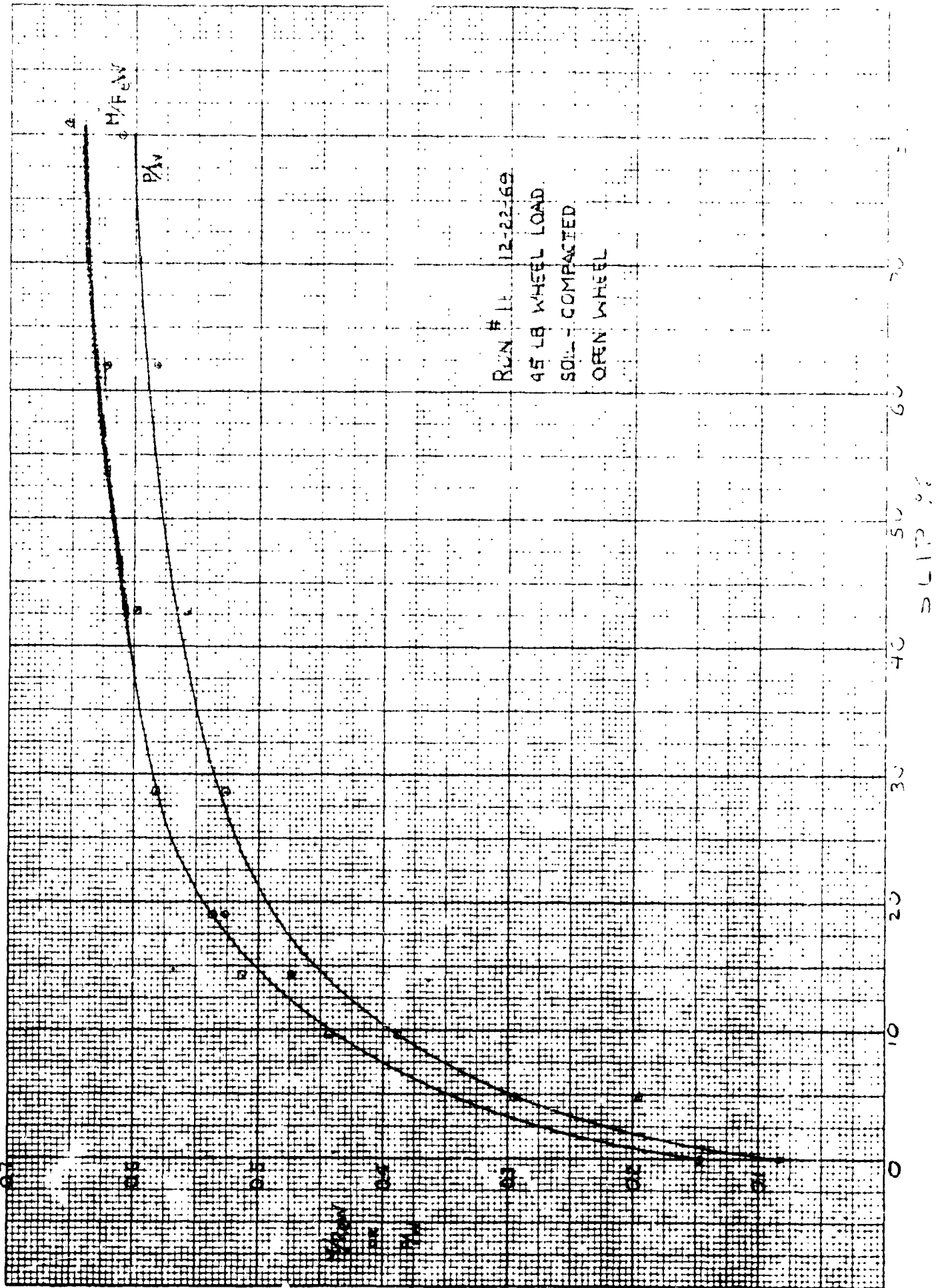


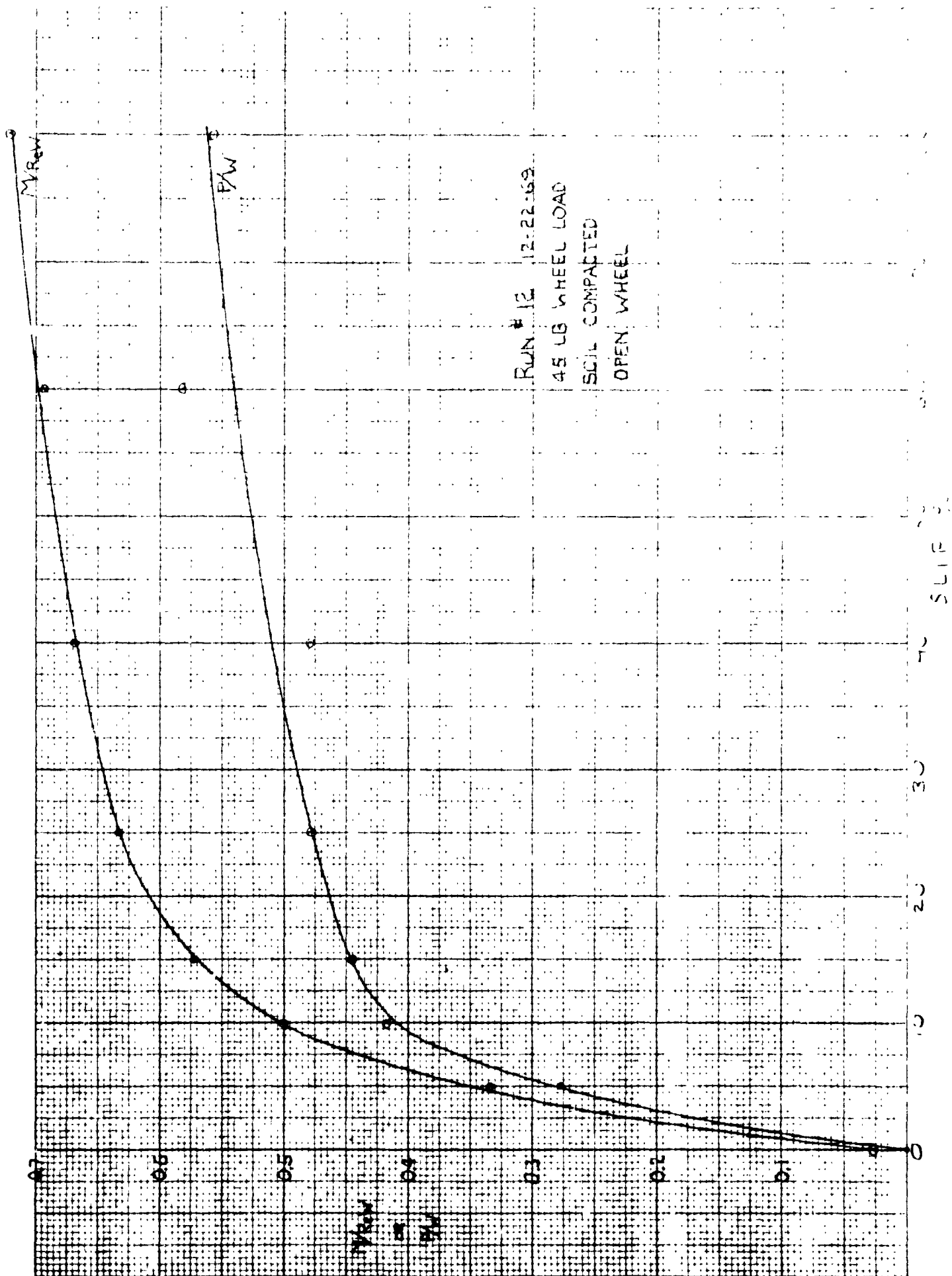


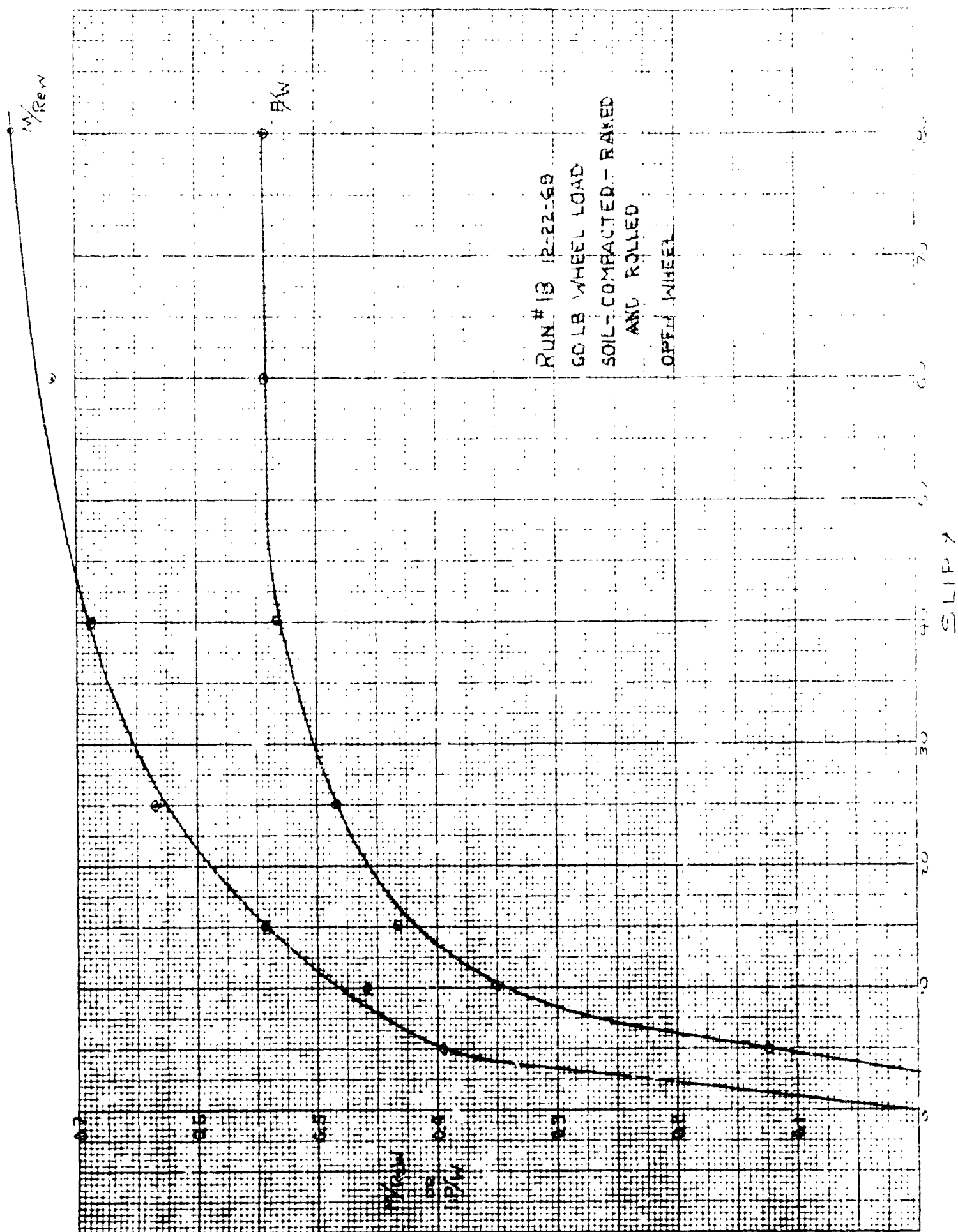
Typical Open Wheel Results in Crushed Silica Sand,  
 Air Dry, Loose Condition





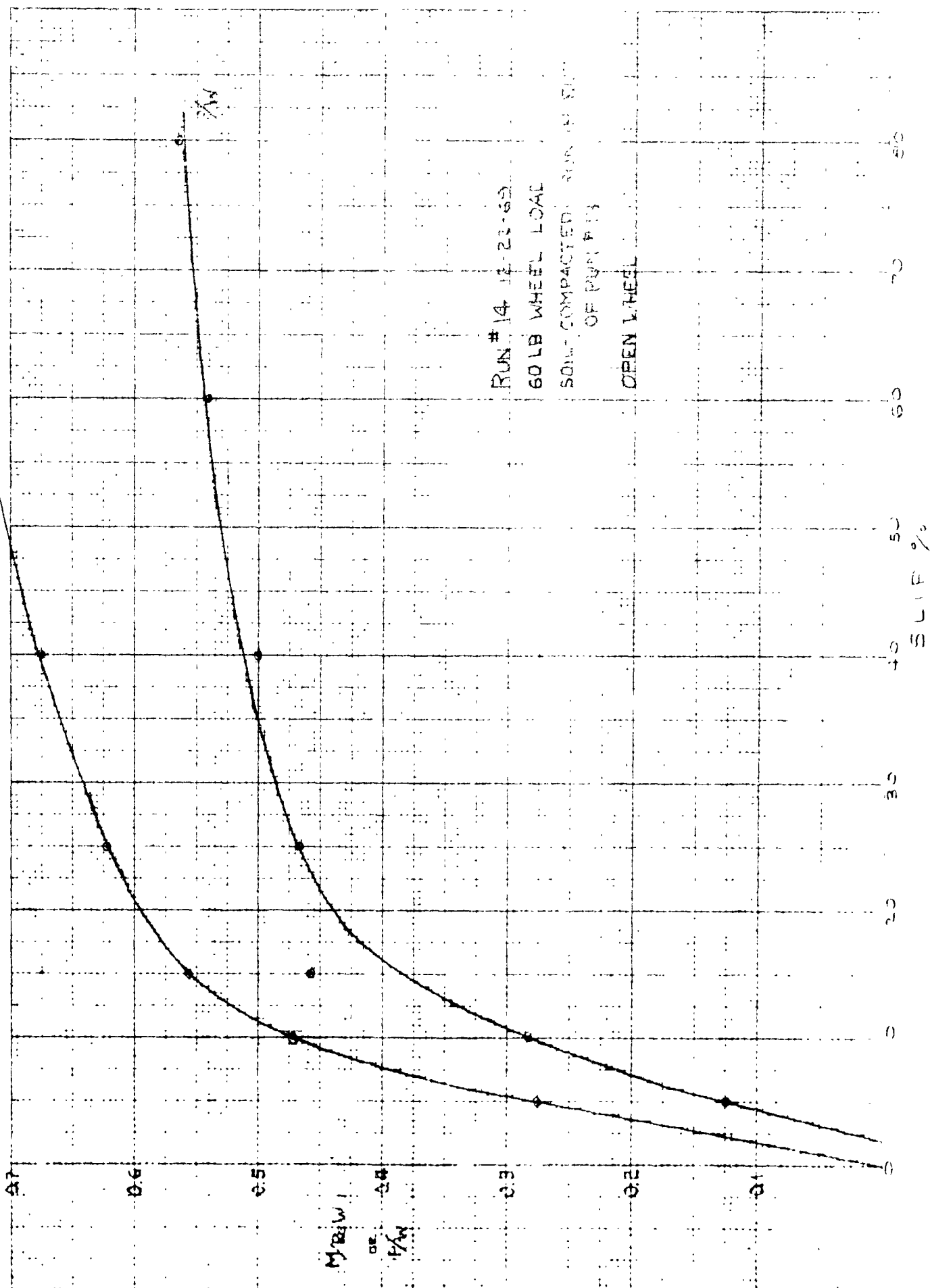


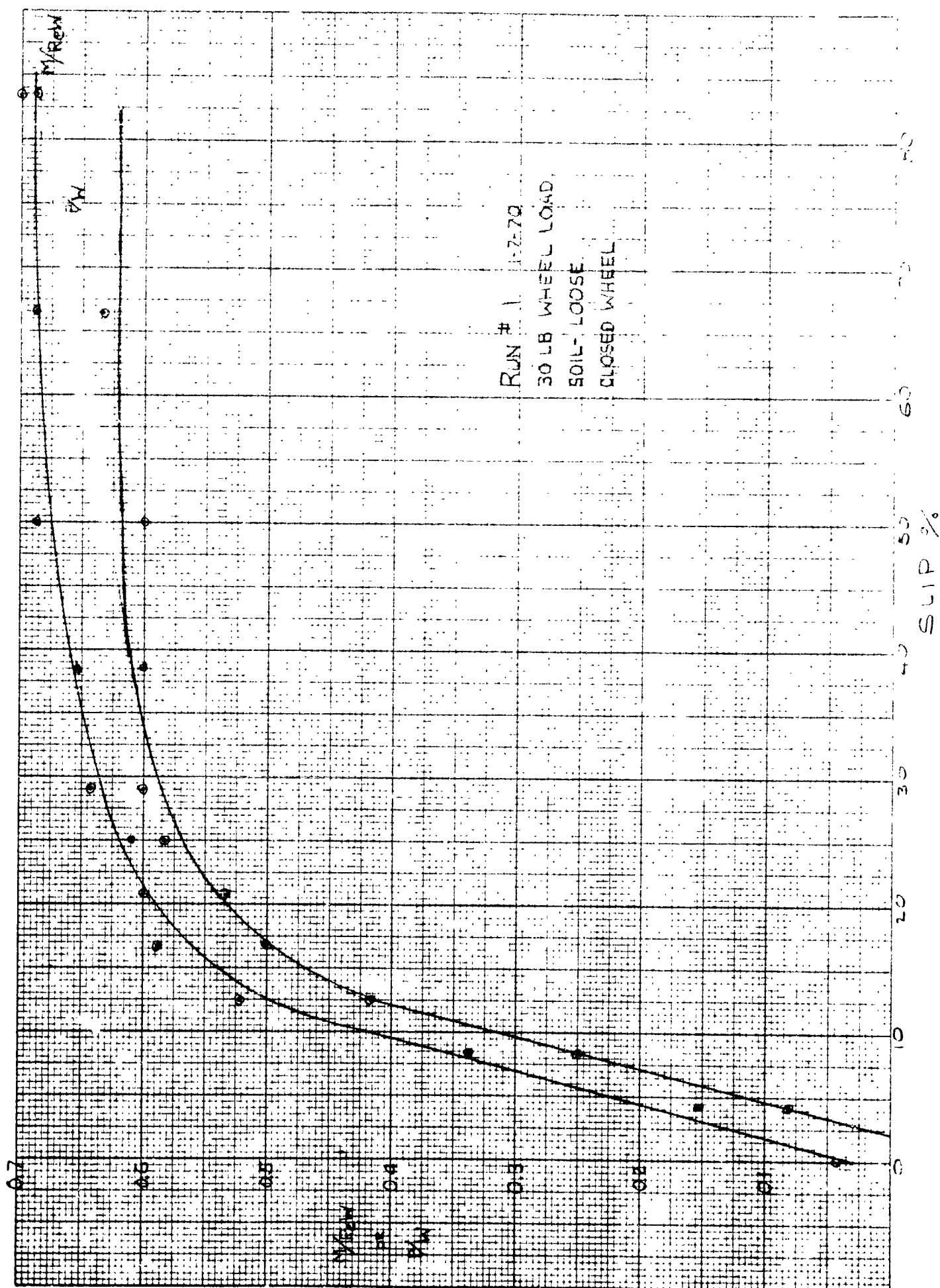




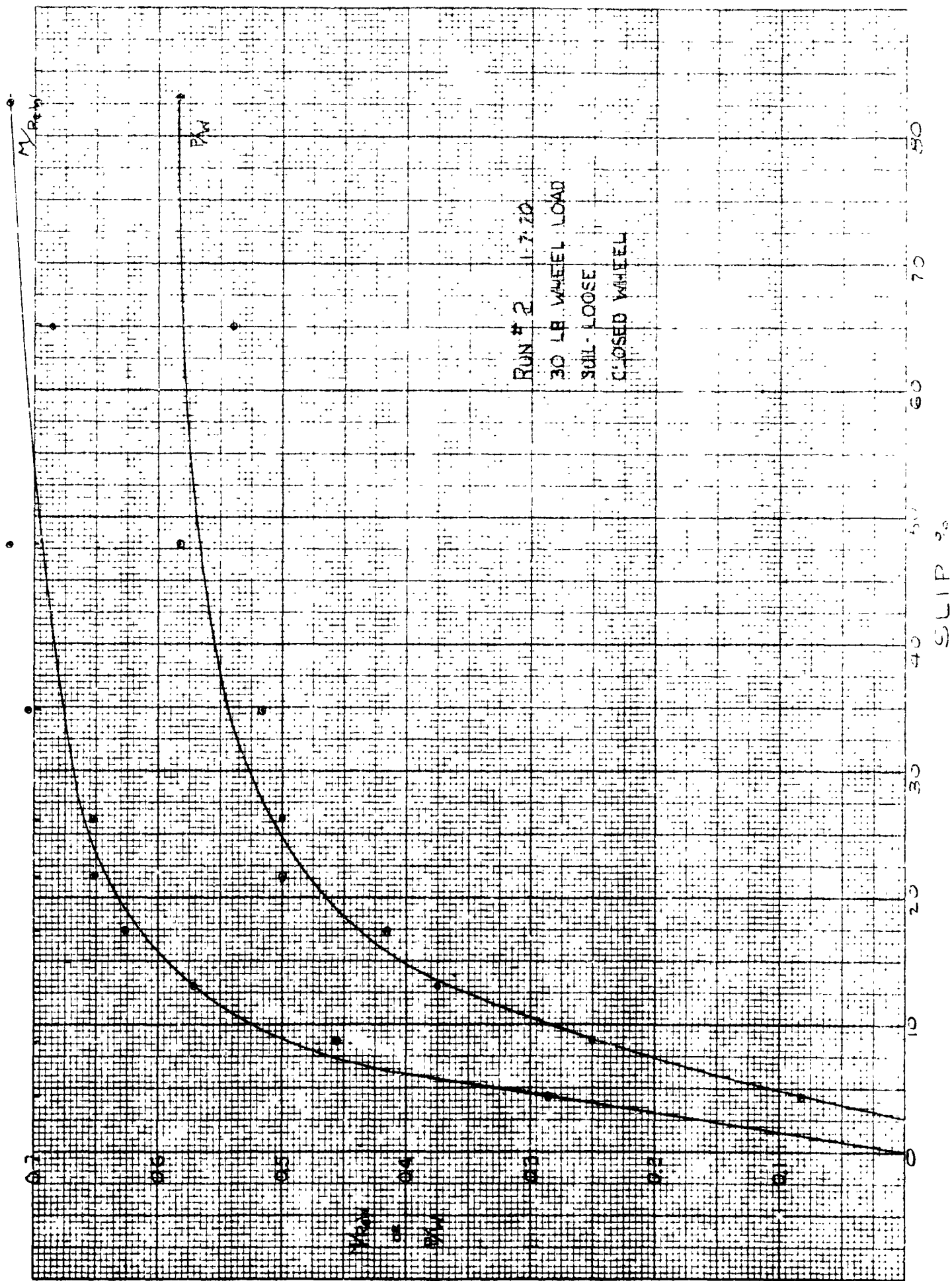
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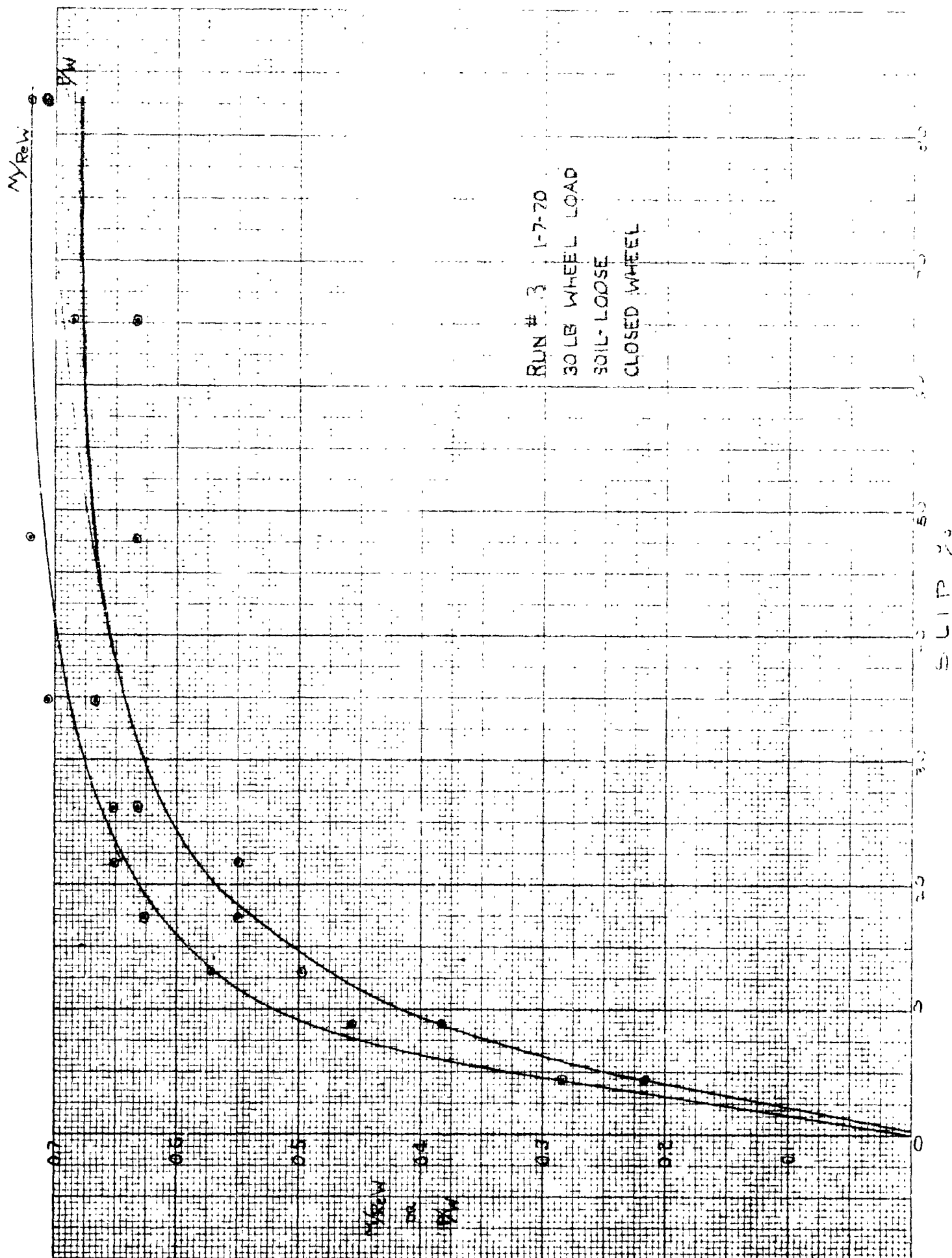
6

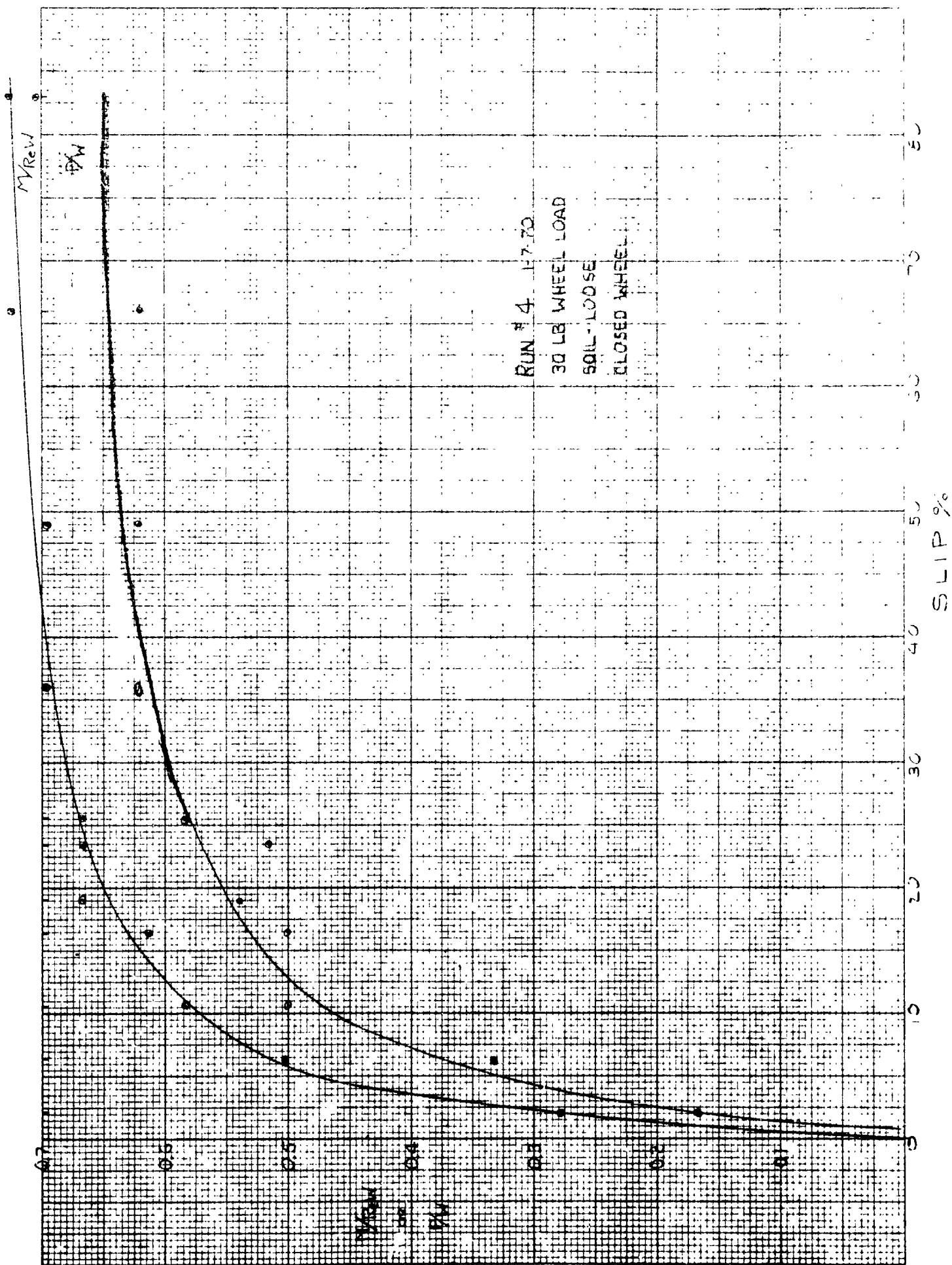




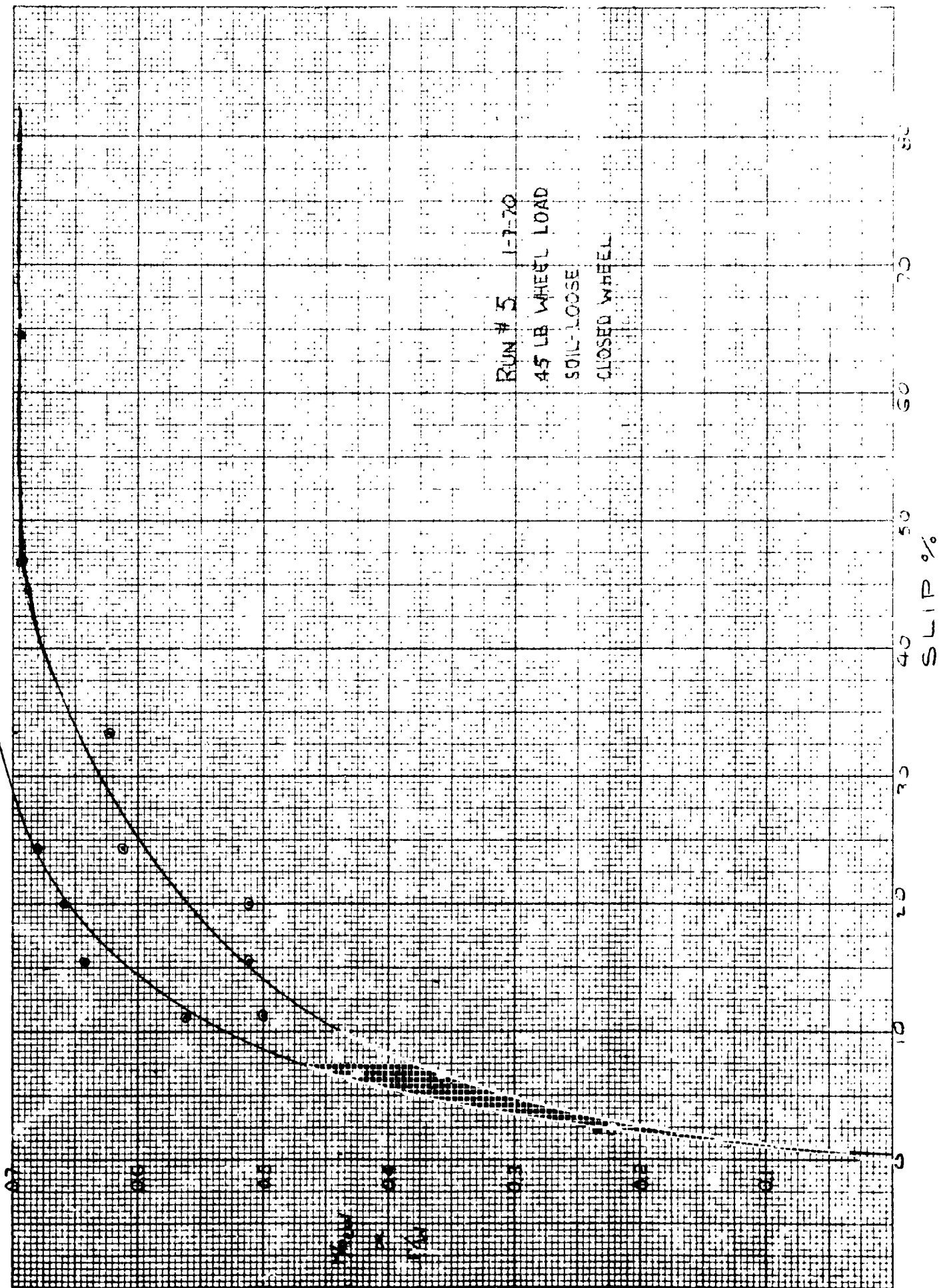


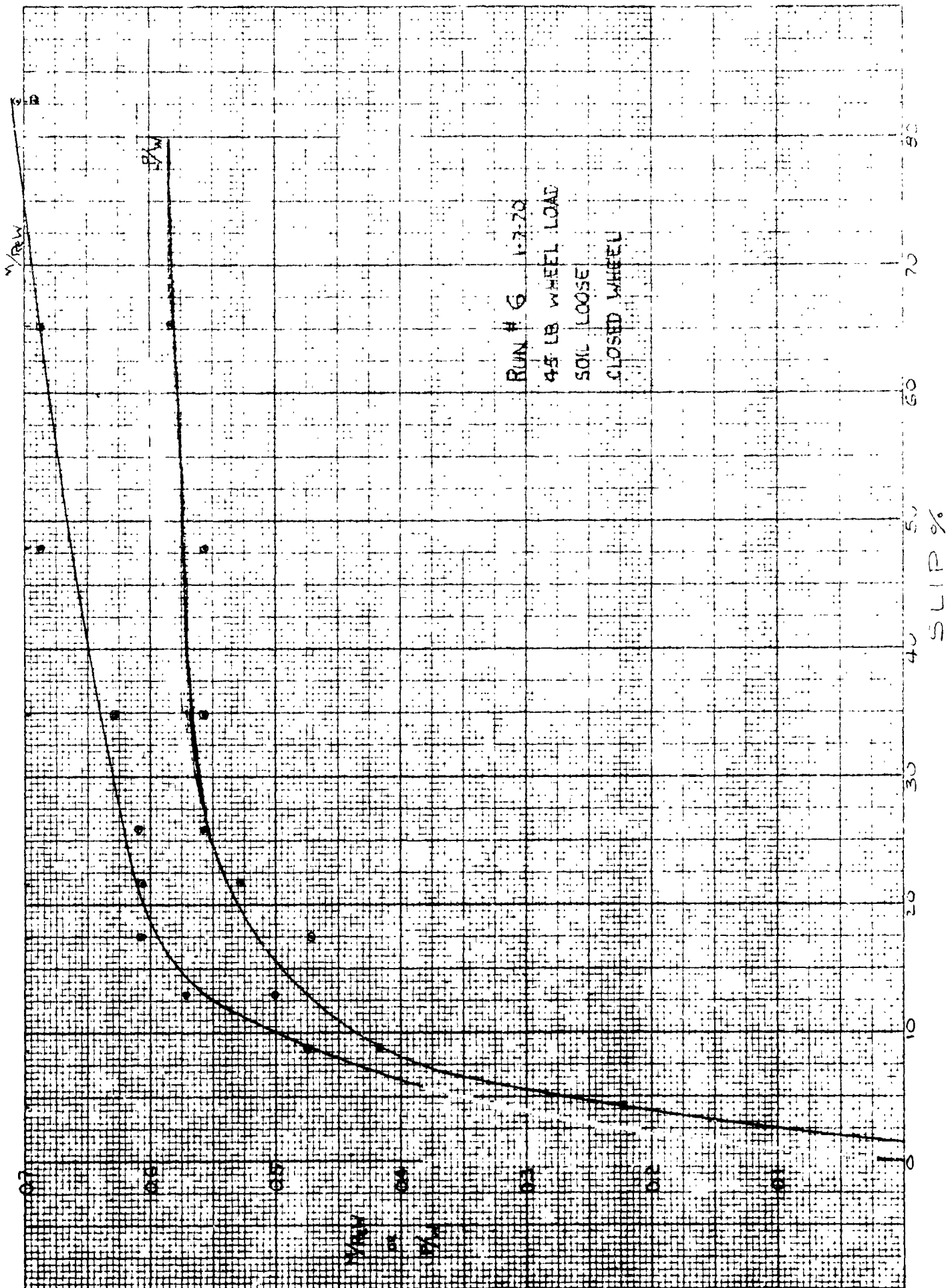






$\frac{1}{R_W}$   
 $\frac{P}{W}$





ReW

ONE  
AGE

Q

SIZE  
J PER

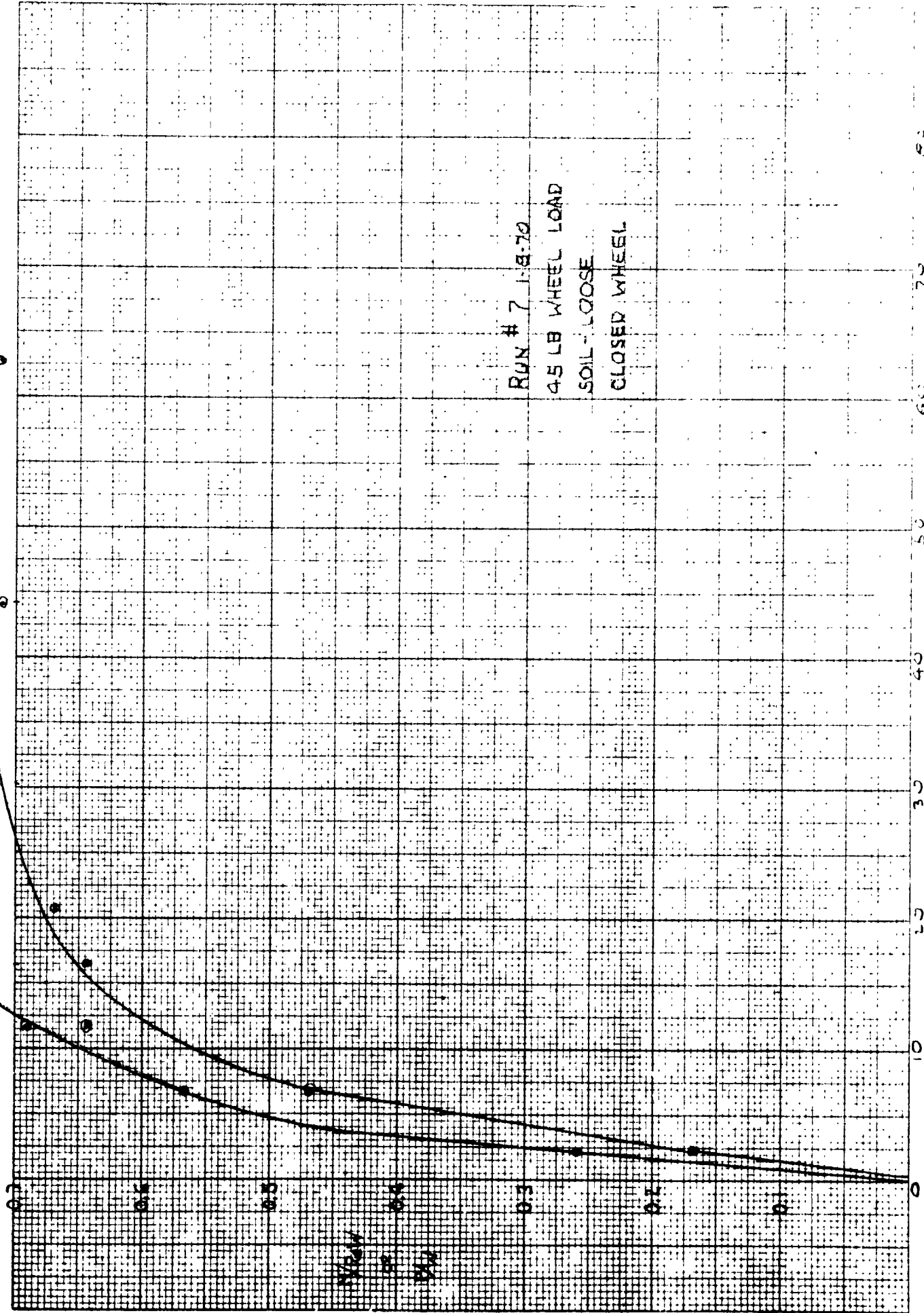
11-20

N

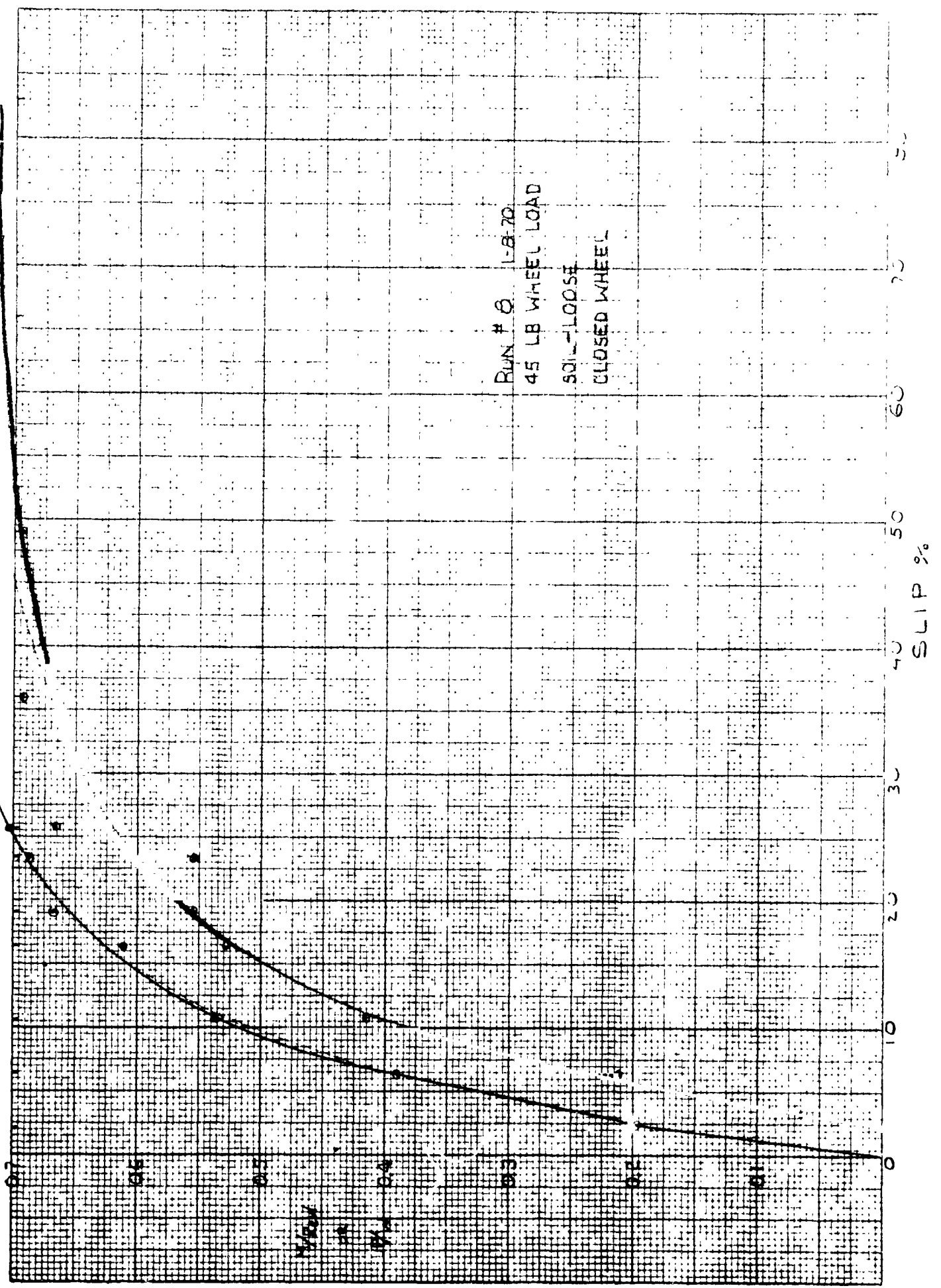
P/W

RUN # 7 1-8-70  
45 LB WHEEL LOAD  
SOIL - LOOSE  
CLOSED WHEEL

SOIL %



M/R.W

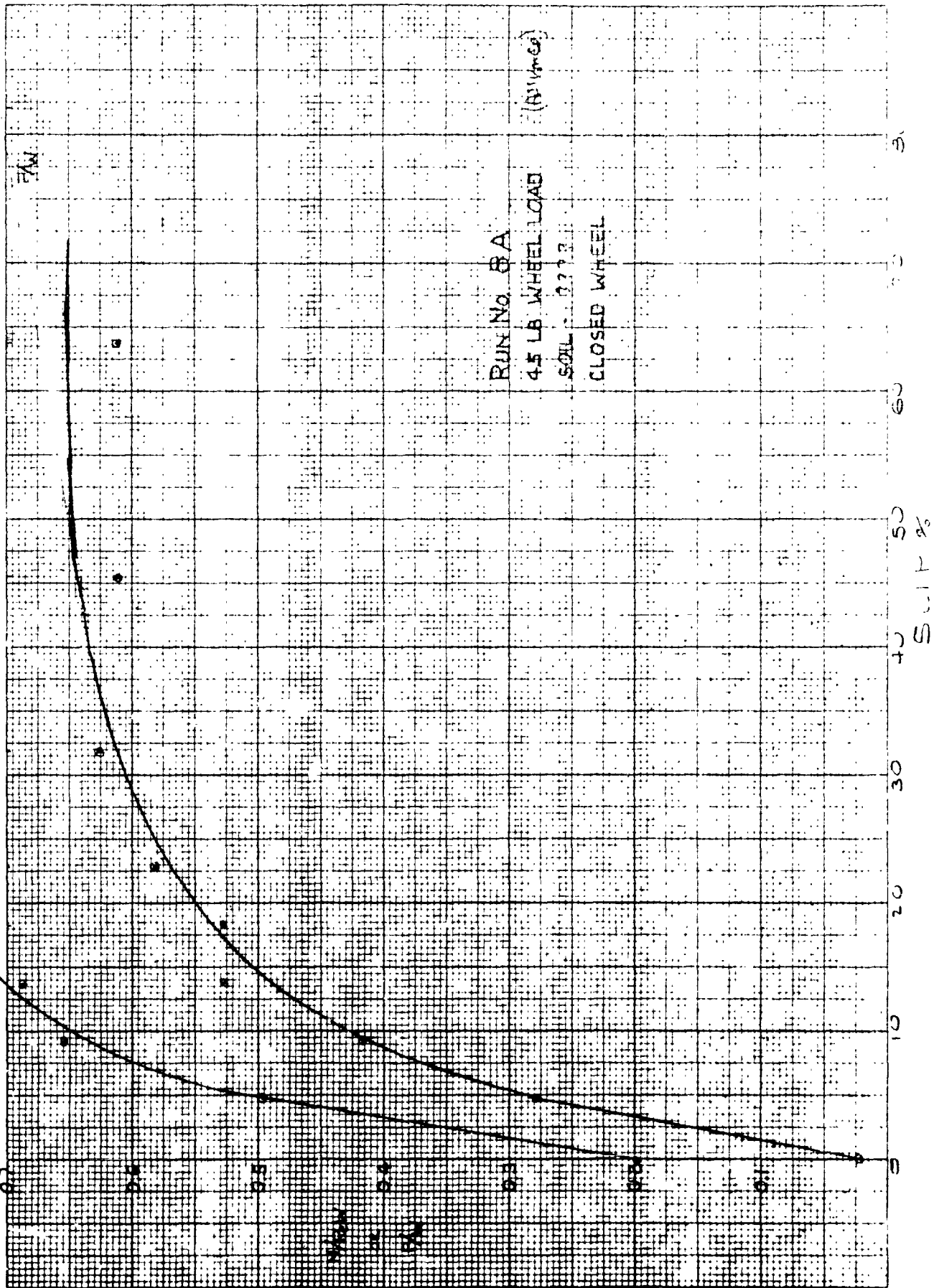




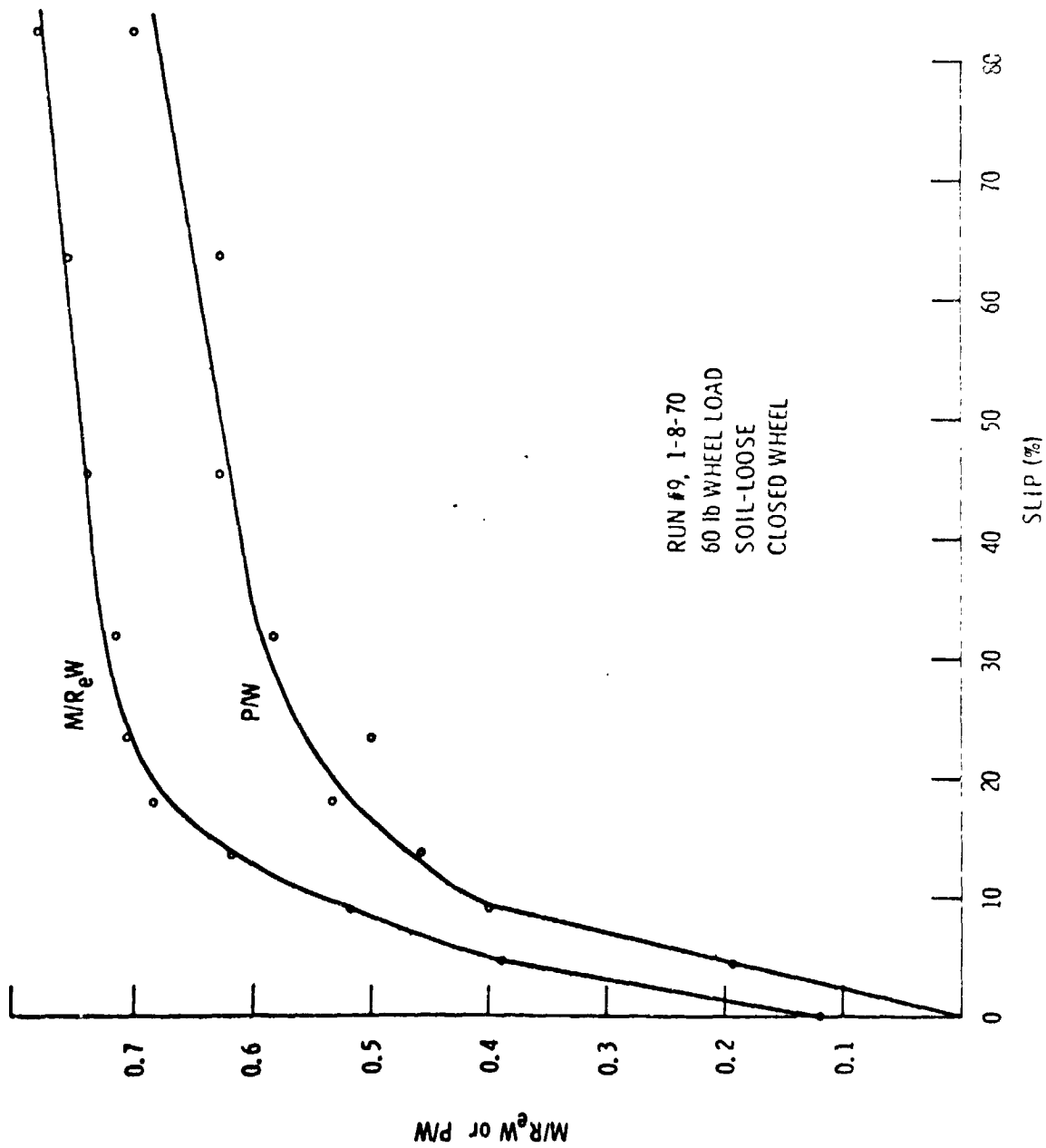
EUGENE DIETZGEN CO  
MADE IN U.S.A.

NO. 341-20 DIETZGEN GRAPH PAPER  
20 X 20 PER INCH

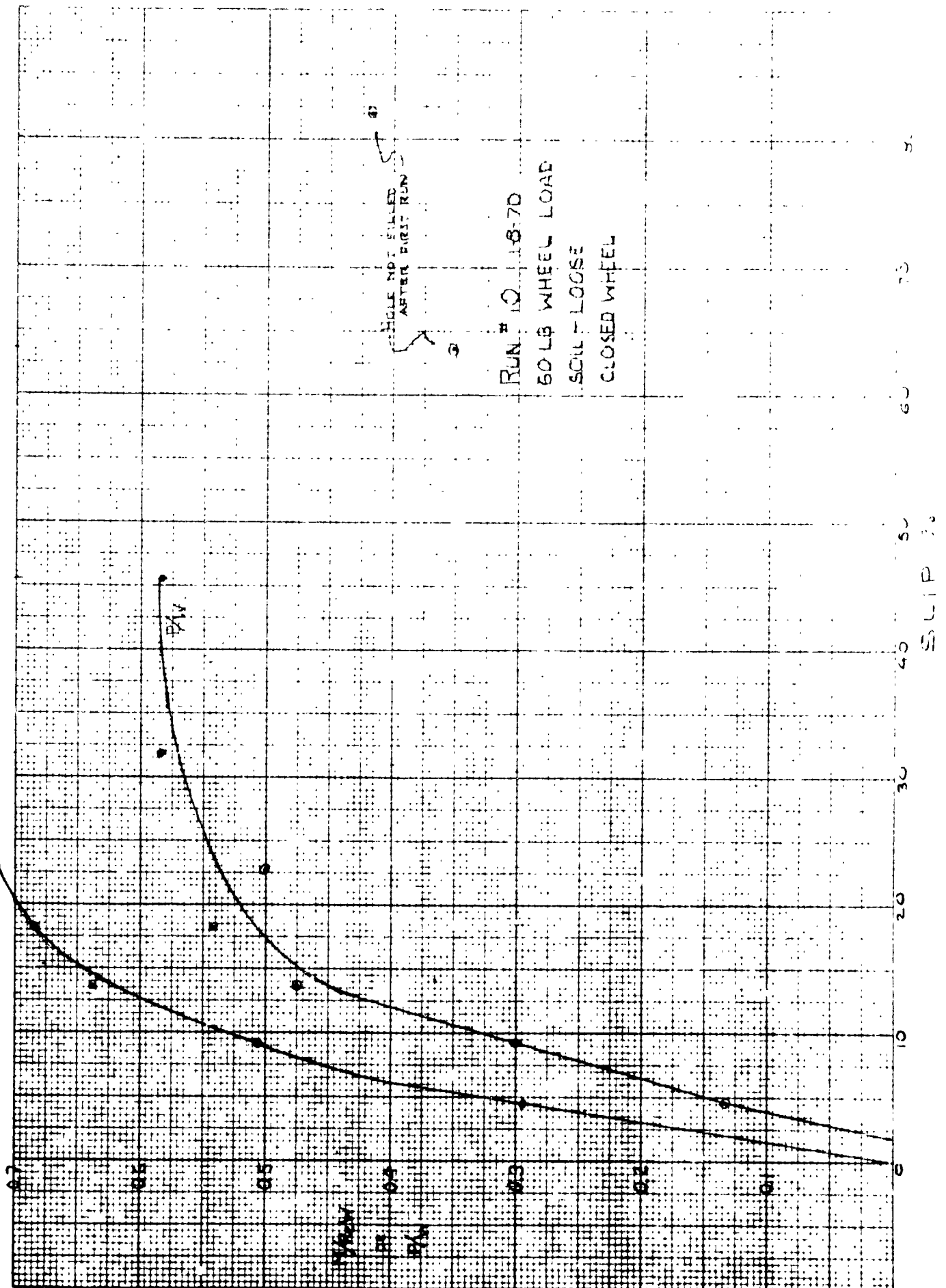
$M/R_{EW}$



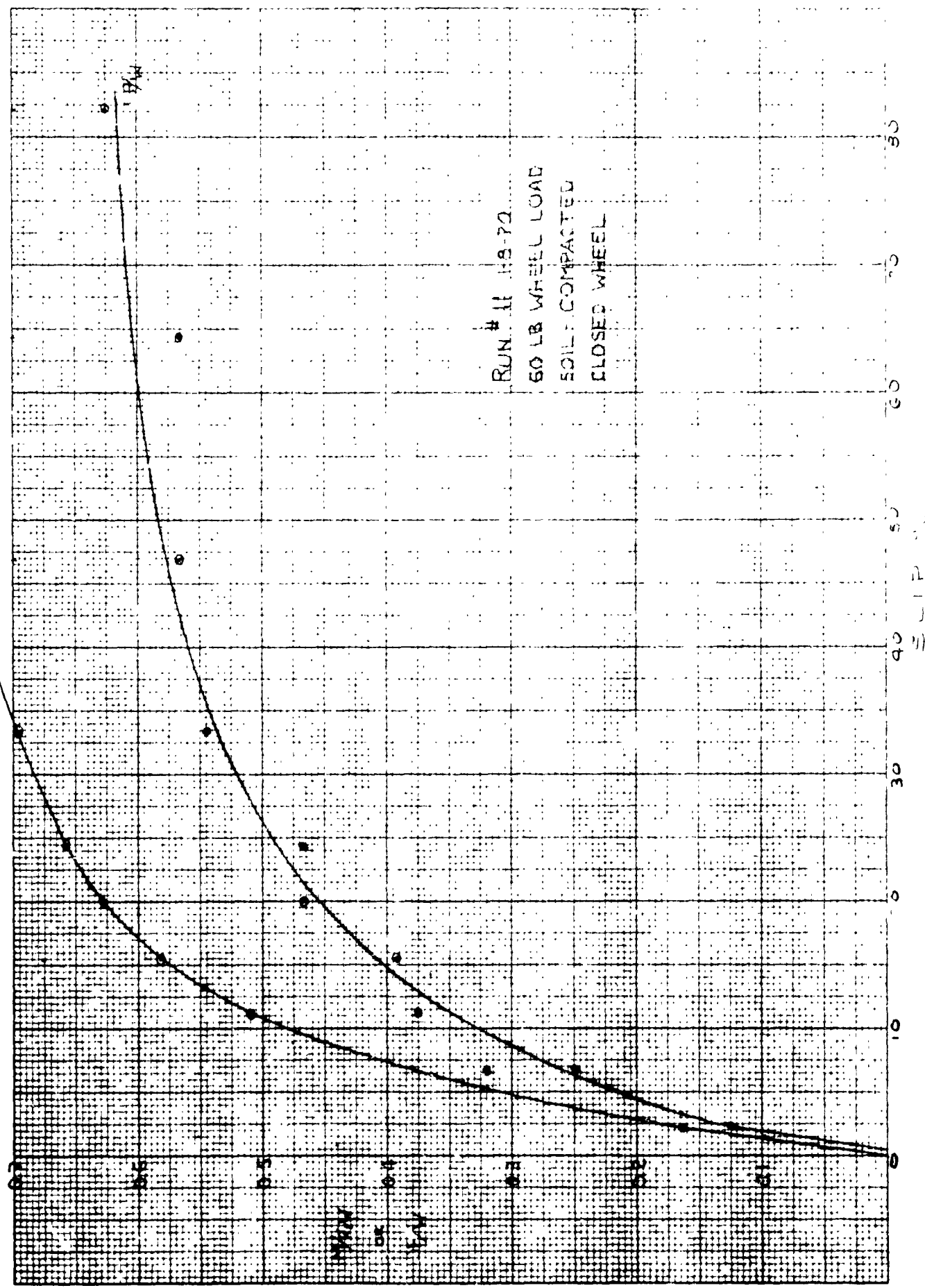




Typical Closed Wheel Results in Crushed Silica Sand,  
 Air Dry, Loose Condition



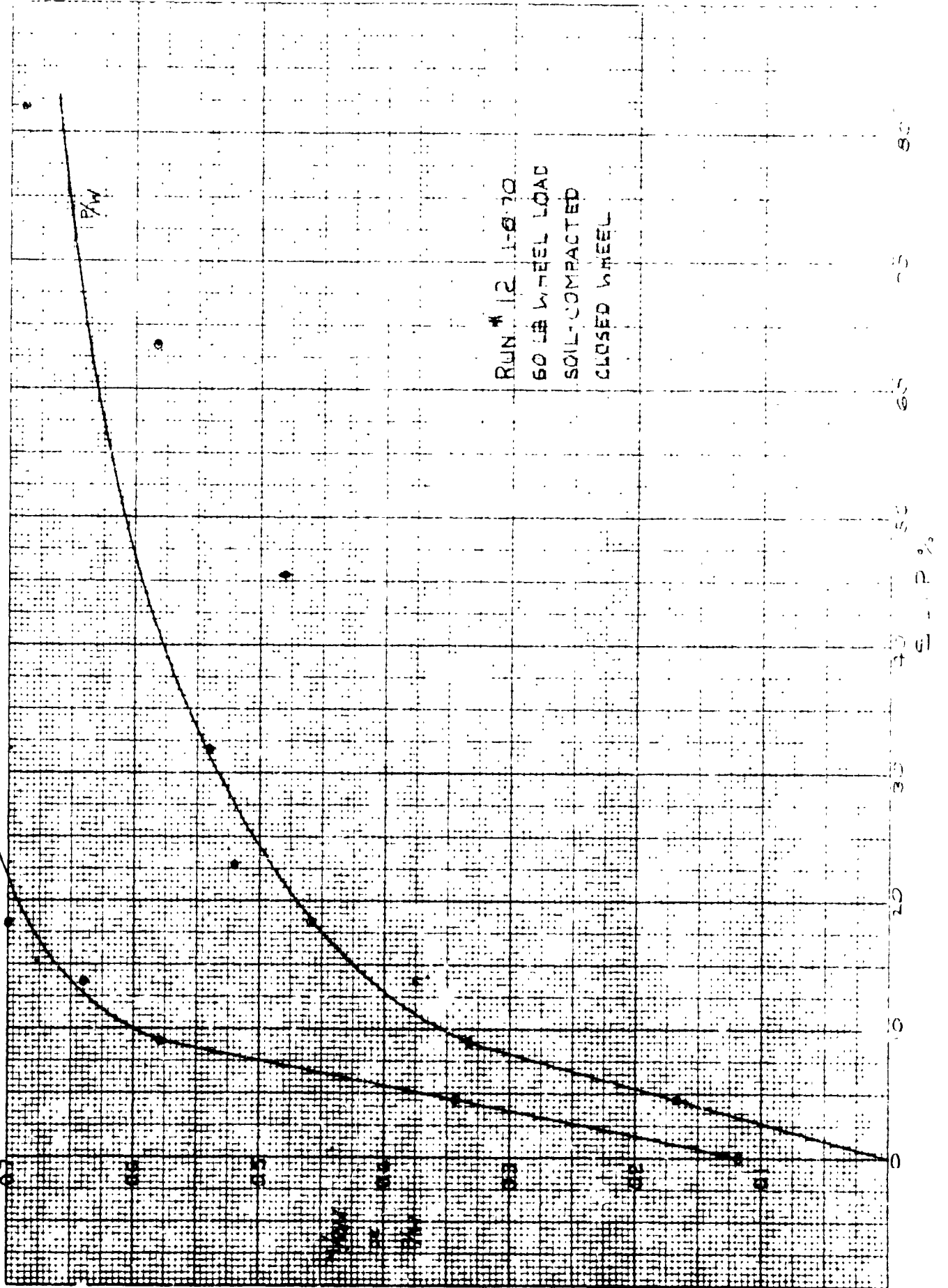
MADE IN U.S.A.  $M/\text{rev}$



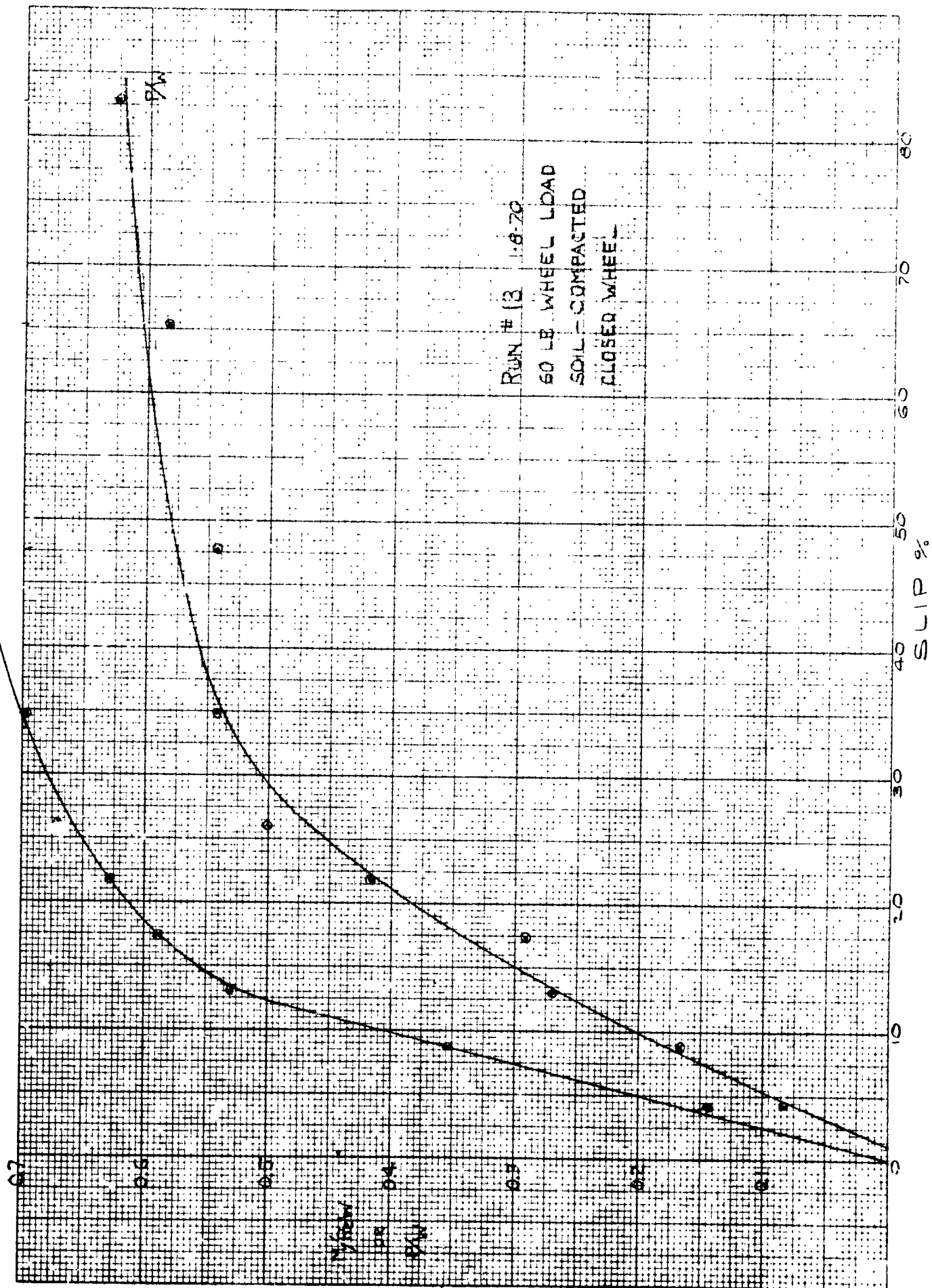
NO. 341-20 DIETZGEN GRAPH PAPER  
20 X 20 PER INCH

EUGENE DIETZGEN CO  
MADE IN U.S.A.

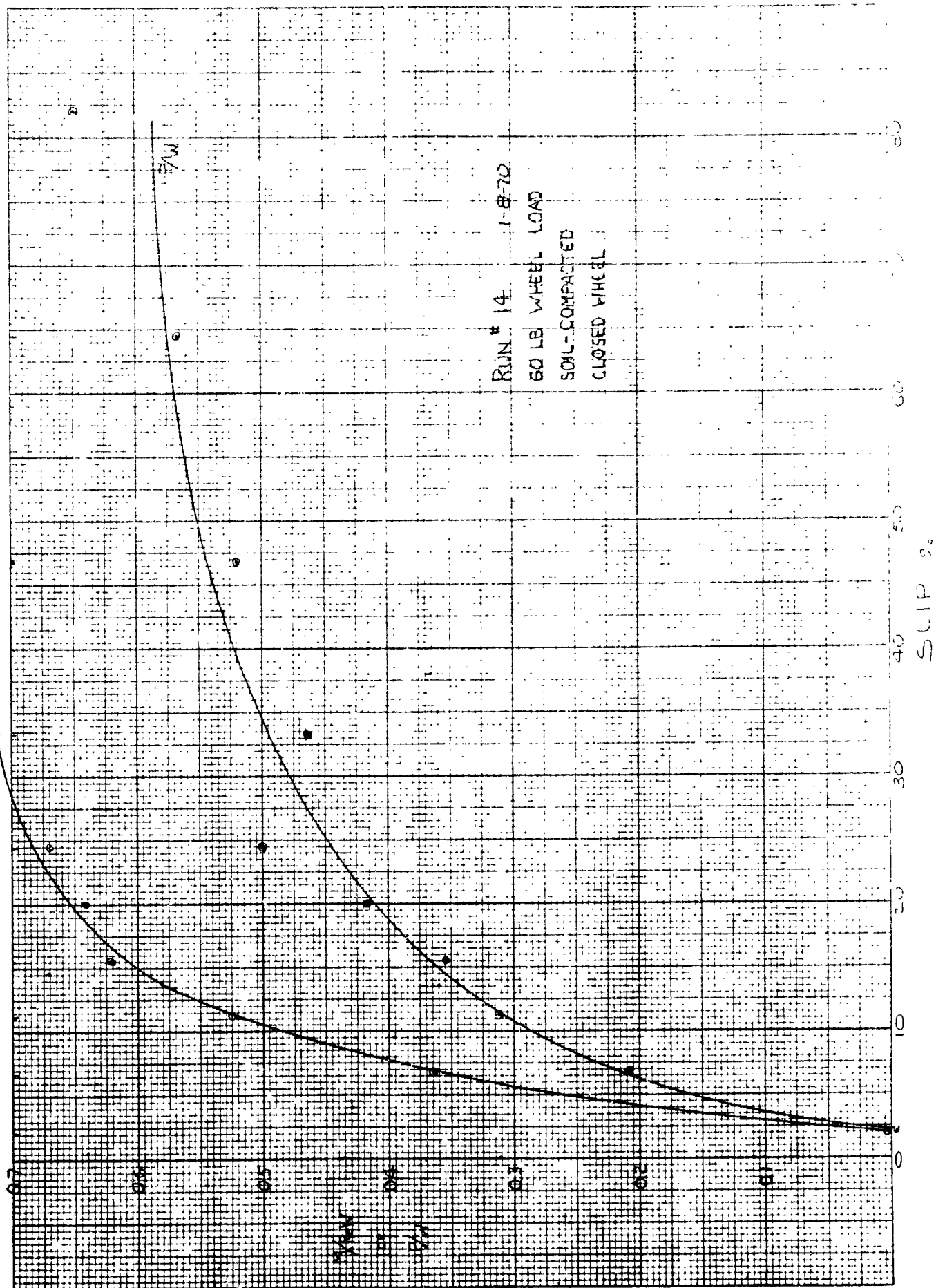
$M/ReW$



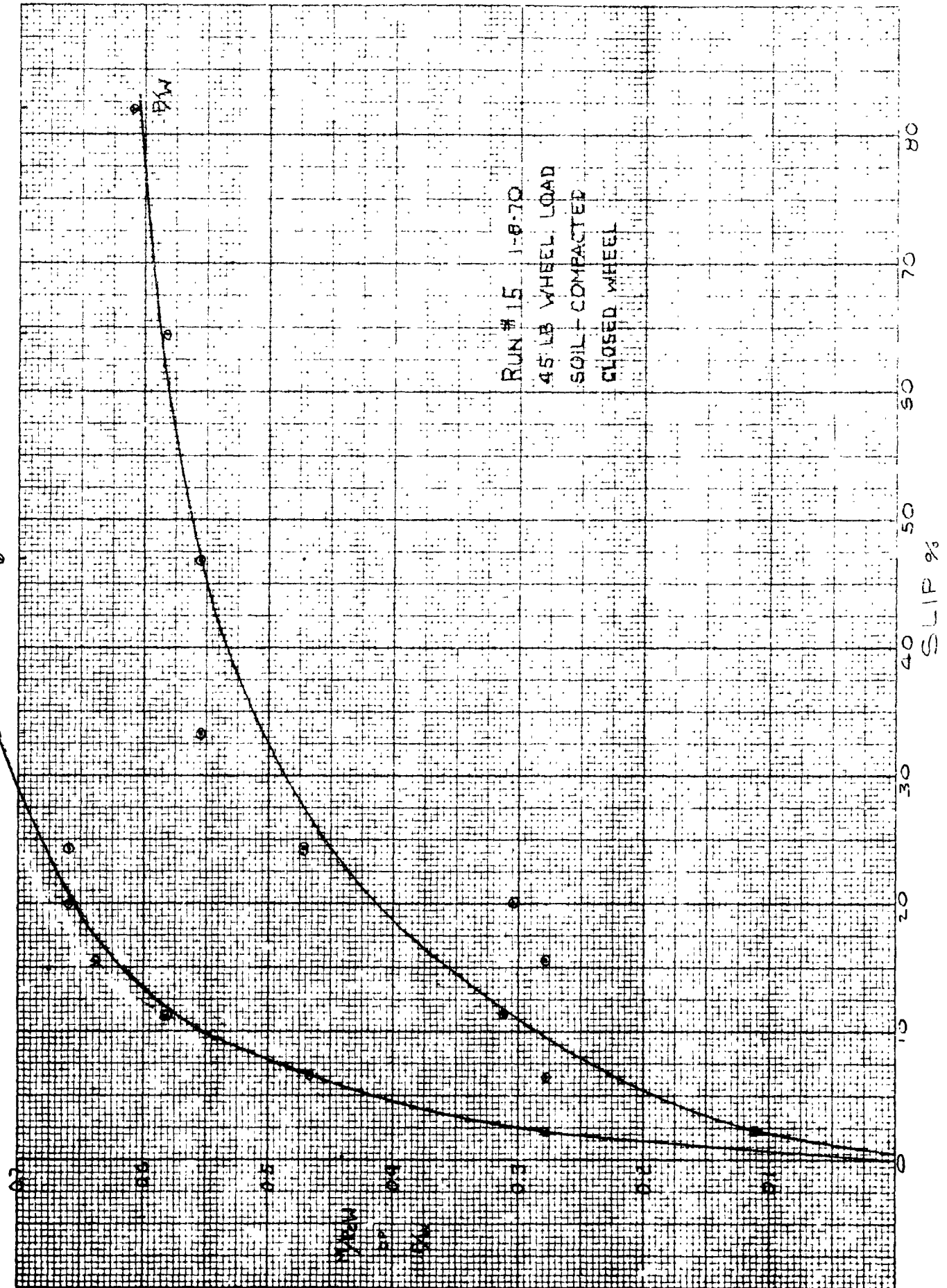
RUN #13 1-8-70  
 60 LB WHEEL LOAD  
 SOIL - COMPACTED  
 CLOSED WHEEL



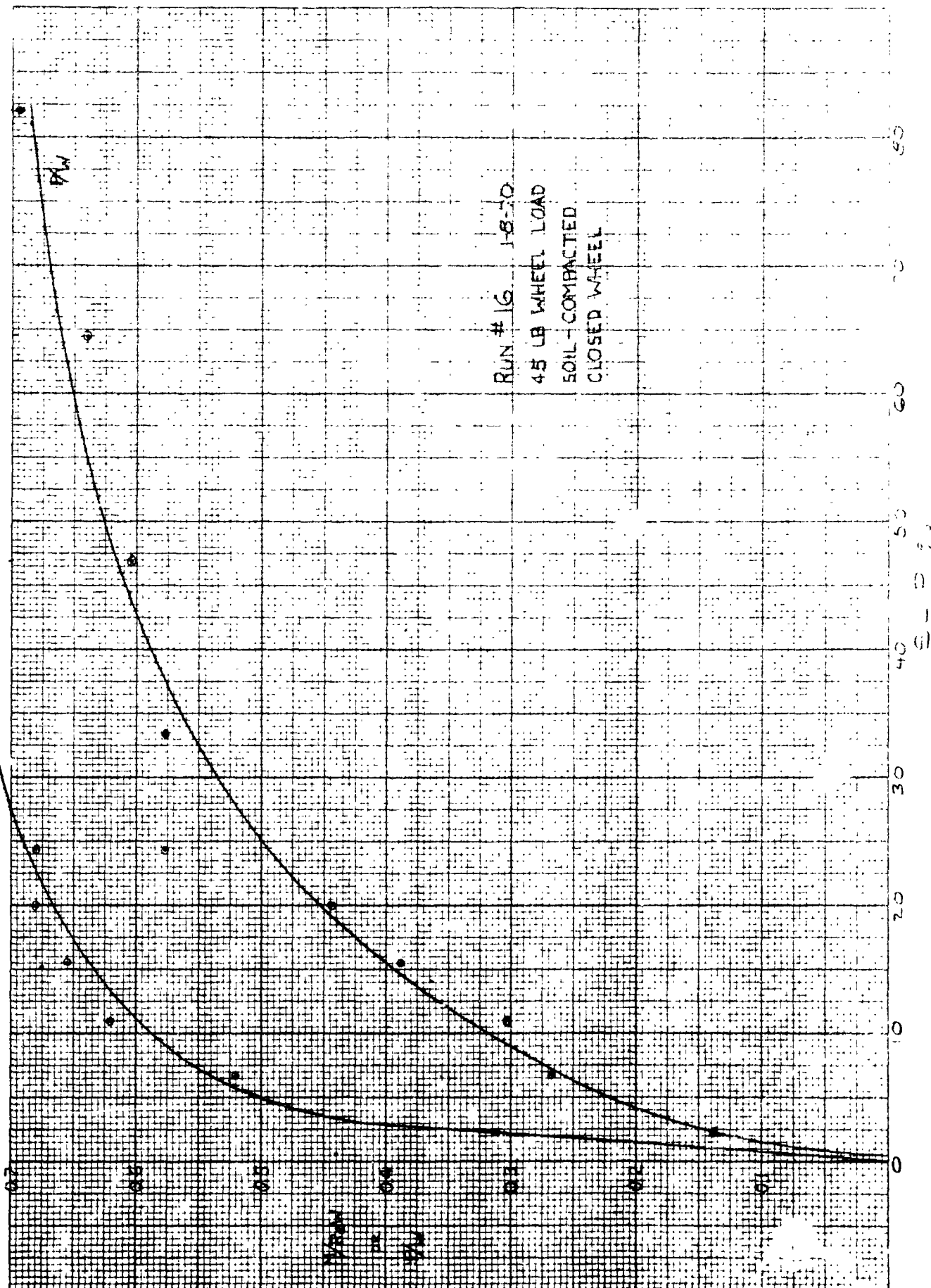
$N/R_{EW}$



MADE IN U.S.A. *M/REW*



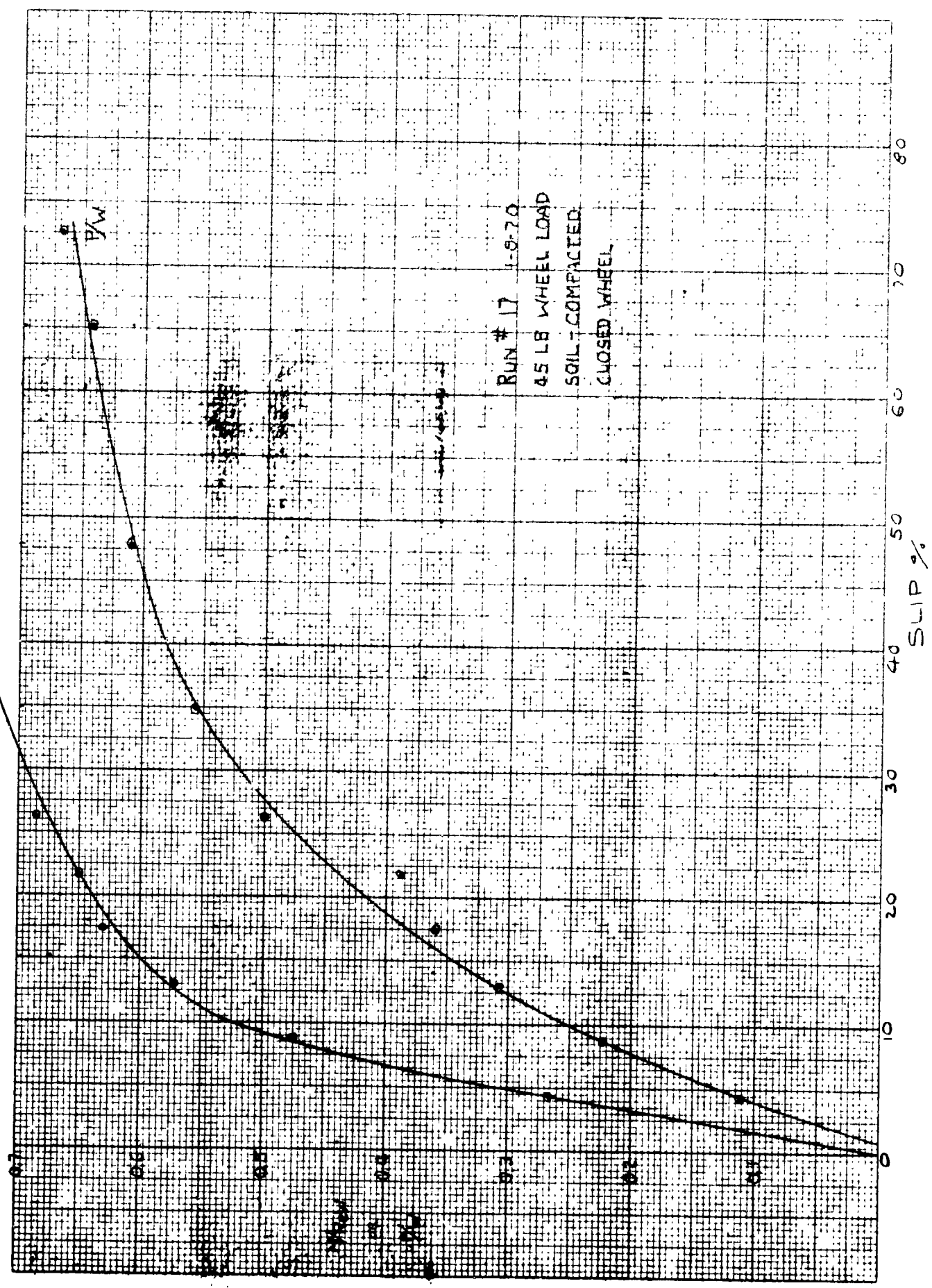
EUGENE DIETZEN CO.  
MADE IN U.S.A.  
 $M/R_{EW}$





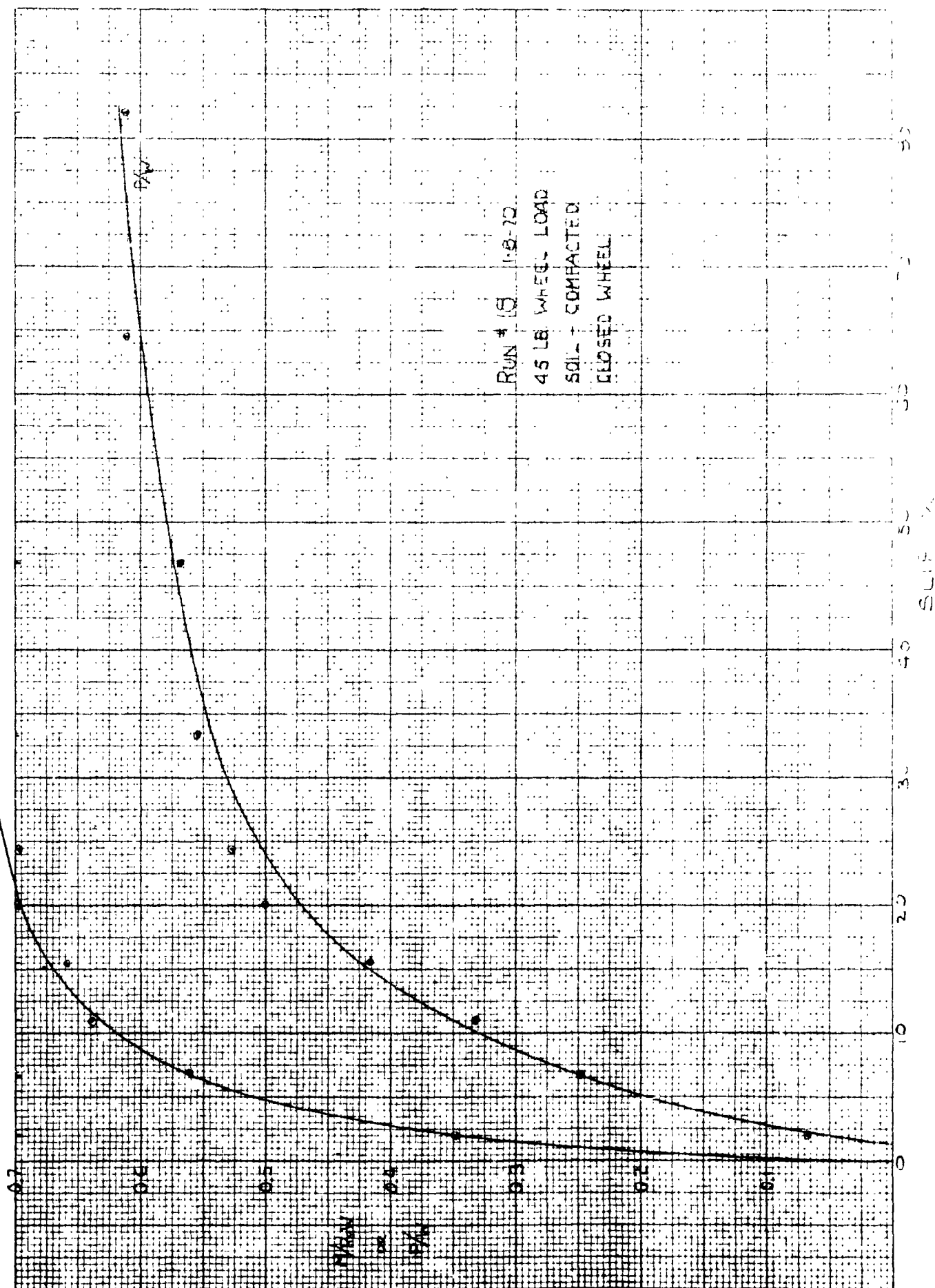
$M_{REW}$

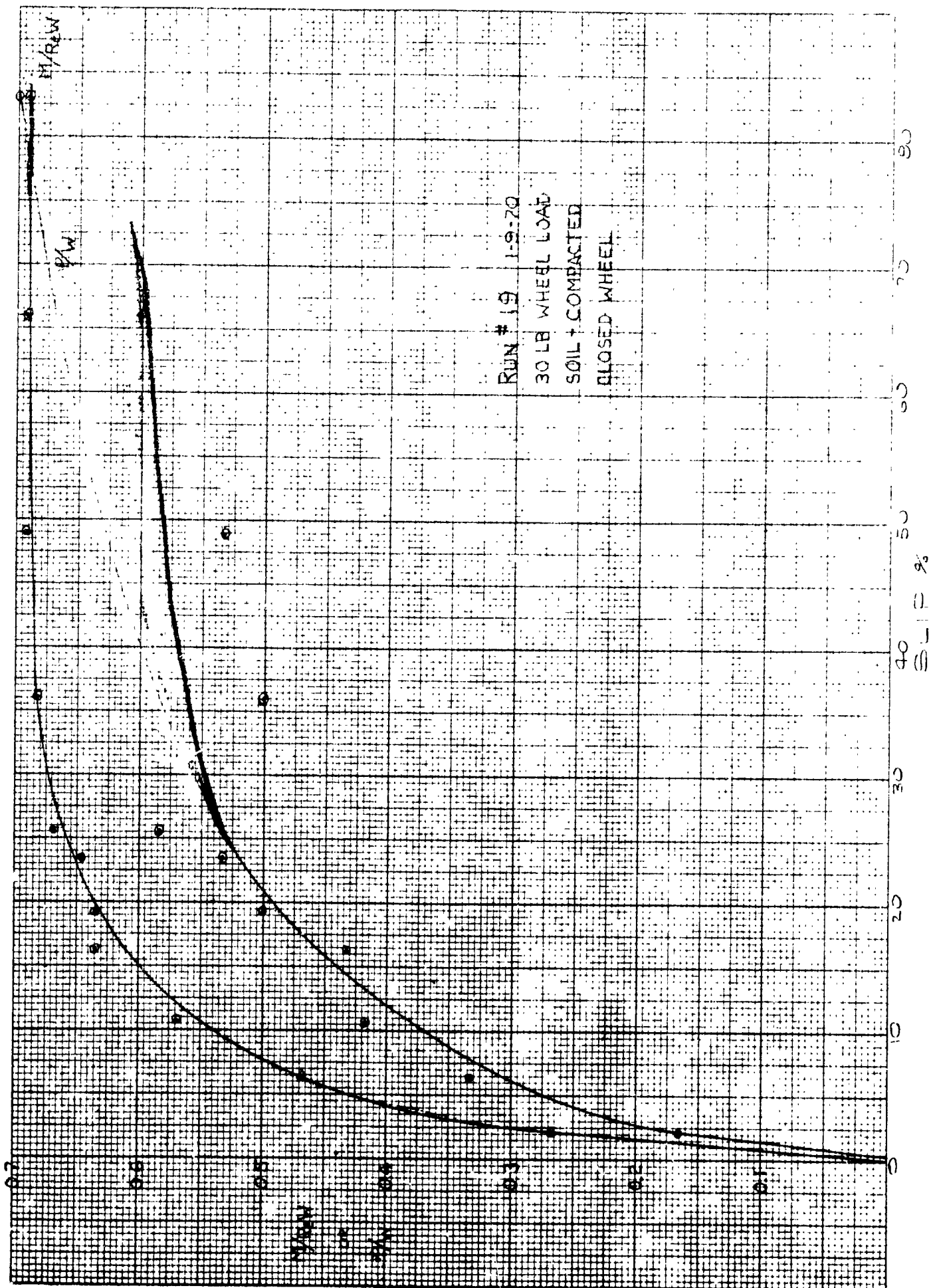
EJUNE DIEZGEN-00  
DATE: 10-5-8



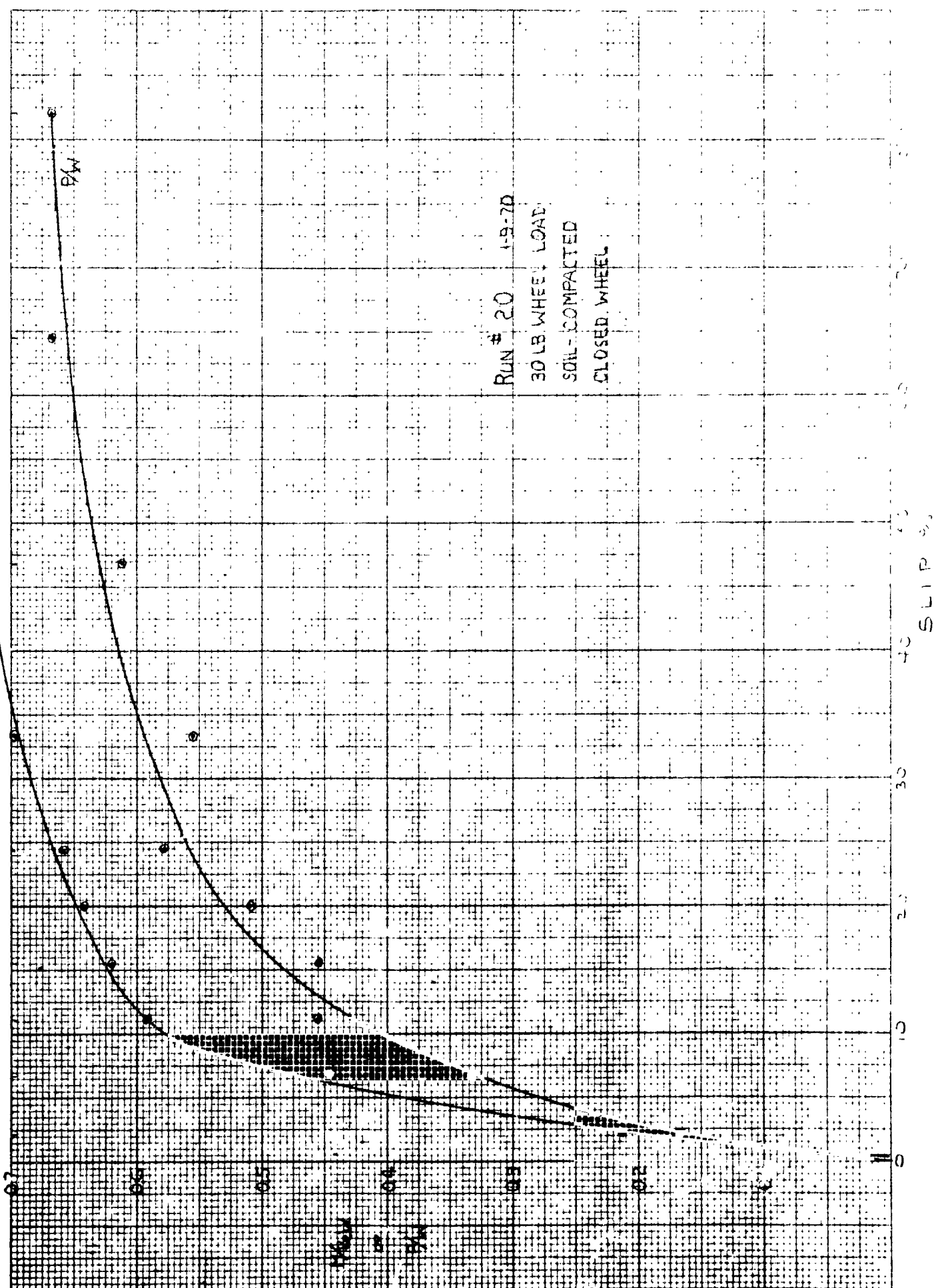
$M/R_{EW}$

9





$M/R_{EW}$

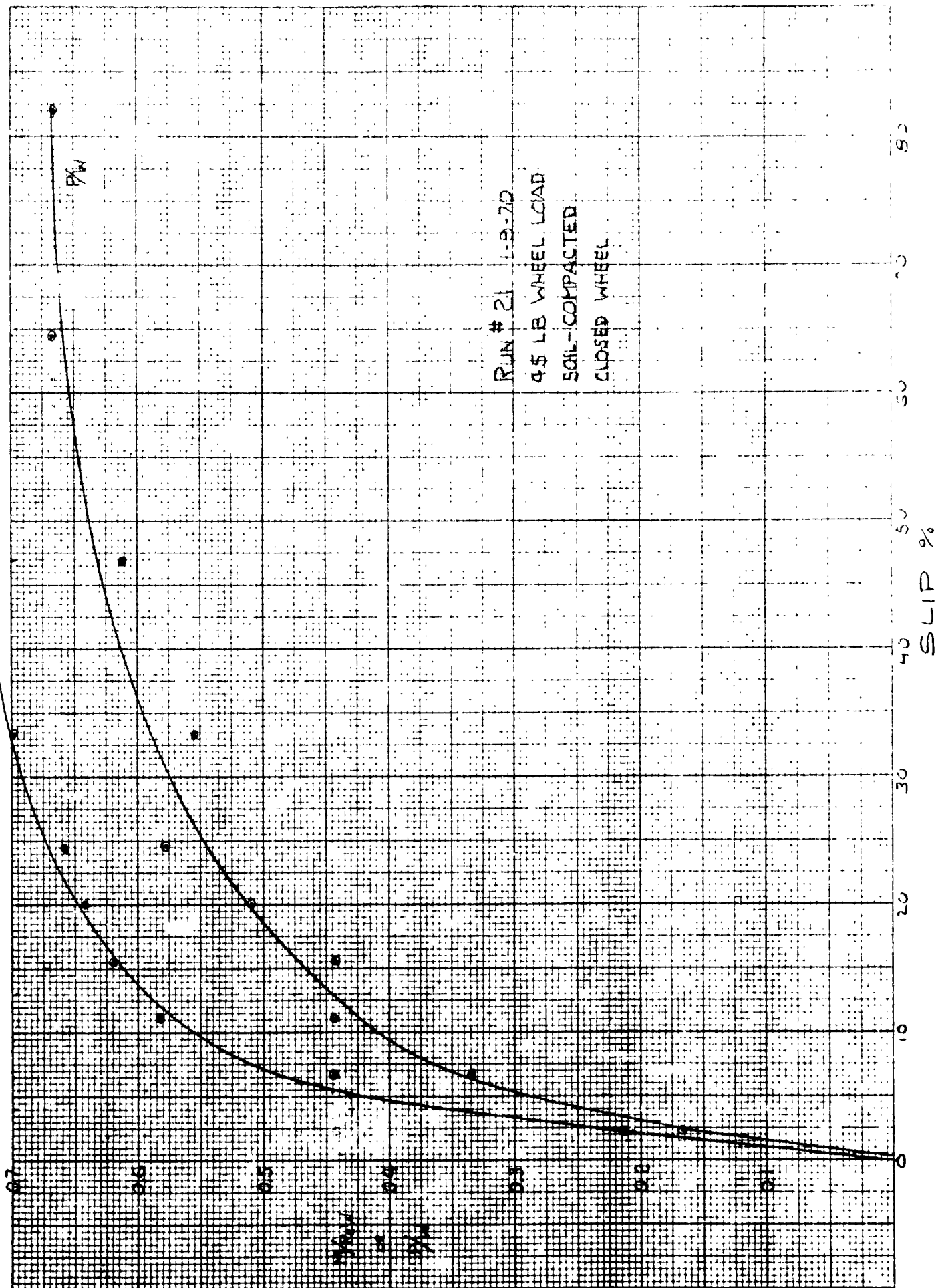


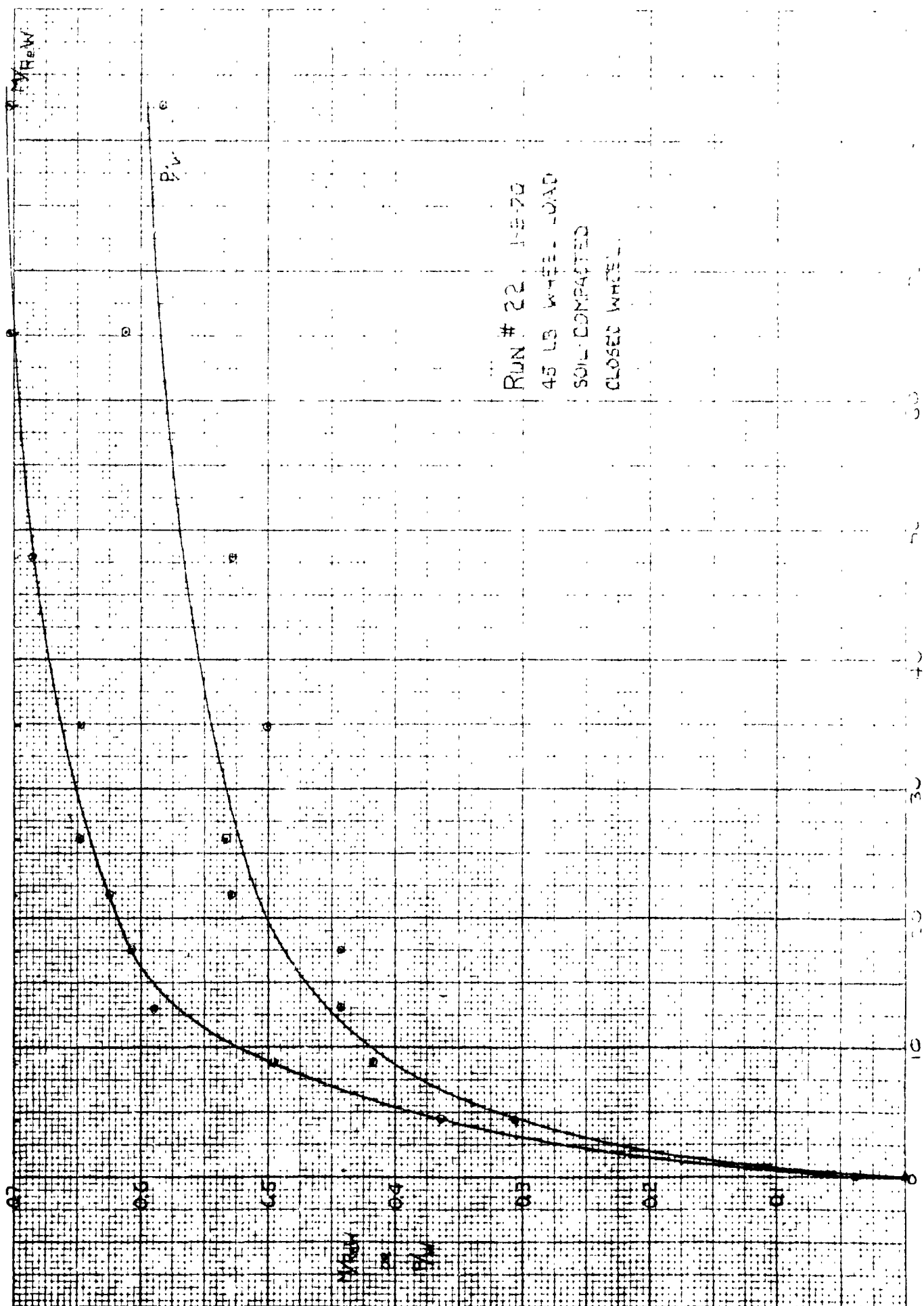
$M_{rew}$

$P/W$

RUN # 21 1-9-70  
45 LB WHEEL LOAD  
SOIL-COMPACTED  
CLOSED WHEEL

SLIP %





# SPECIFICATION

AC ELECTRONICS

DEFENSE RESEARCH LABORATORIES  
GENERAL MOTORS CORPORATION  
8787 HOLLYSTER AVE. GILBERT, CALIFORNIA 95027

NO.	REV
ES10115	
SHEET 1 OF 4	
CODE IDENT NO. 13160	

## WHEEL ASSEMBLY DUAL-MODE LUNAR ROVING VEHICLE (DLRV) ENGINEERING SPECIFICATION FOR

1. SCOPE. This specification establishes the design, performance, and acceptance requirements for the Wheel Assembly of the Dual-Mode Lunar Roving Vehicle (DLRV).
2. APPLICABLE DOCUMENTS. The following documents form a part of this specification to the extent specified herein. Unless a specific issue is noted in this listing, the issue in effect on date of contract shall apply.

### STANDARDS

#### Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of U. S. Military Property

### DRAWINGS

#### AC-DRL

RSK 20141	Wheel Assembly - Open
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### PUBLICATIONS

#### AC-DRL

AC-STD-1	Workmanship
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### 3. REQUIREMENTS

#### 3.1 Functional Characteristics

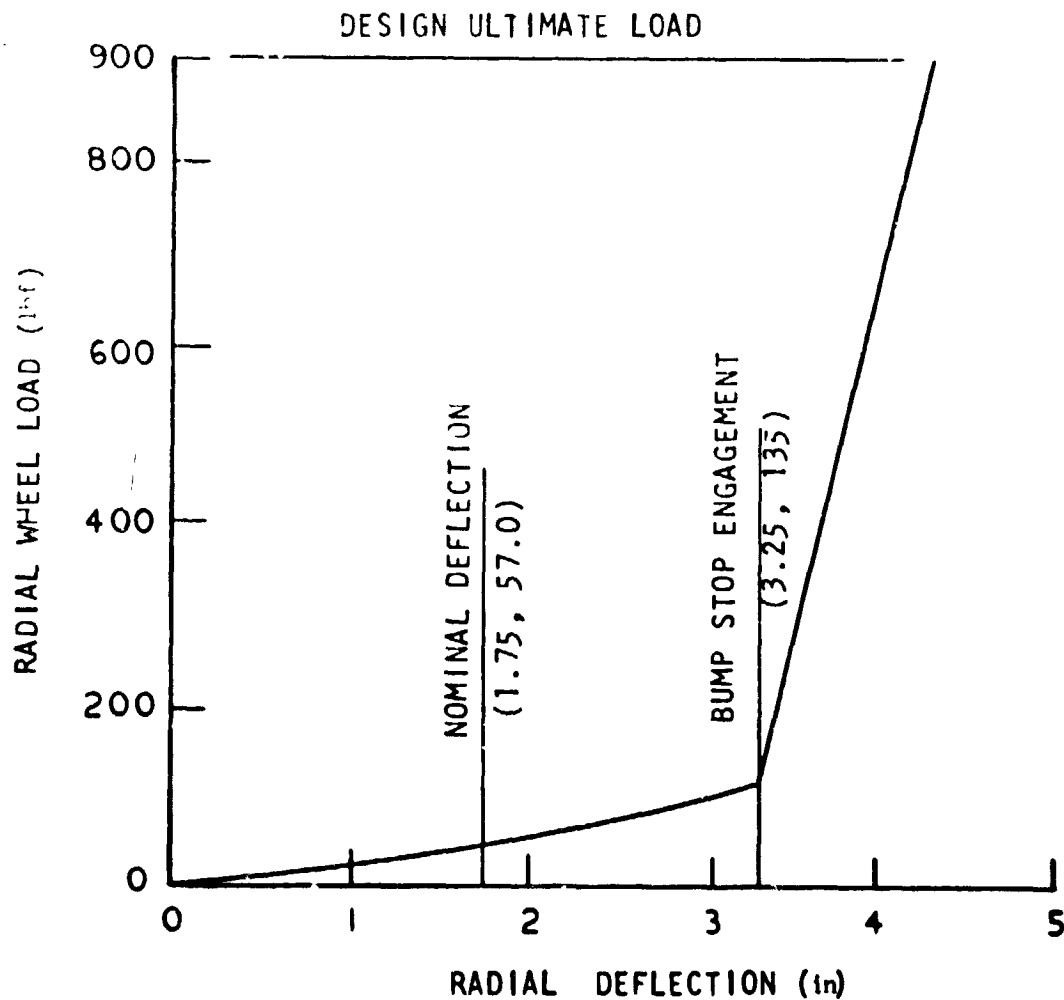
3.1.1 Wheel Deflection: The wheel assembly (mesh tire) shall deflect  $1\frac{3}{4} \pm 1/4$  inches with an applied vertical load of 57 lbs(f). The minimum deflected radius is 14.25 inches. The nominal total deflection shall be in accordance with Figure 1.

# SPECIFICATION

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5-2

FIGURE 1

DLRV WHEEL - LOAD/DEFLECTION CHARACTERISTICS



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SHEET 3 OF 4	
CODE IDENT NO. 13160	

## 3.2 Design Characteristics

3.2.1 Baseline: The wheel assembly shall be to the baseline shown in RSK 20141.

3.2.2 Weight: The total weight of each wheel assembly shall not exceed 12.4 lbm, including tire, hub, and attachment hardware.

3.2.3 Freewheeling: Each wheel assembly must be capable of being disconnected from the motive power source, and put in a freewheeling condition.

3.2.4 Workmanship: Workmanship shall be in accordance with AC STD 1.

3.2.5 Identification and Marking: The assembly shall be identified by name plates or markings as appropriate and affixed in accordance with MIL-STD-129 and MIL-STD-130. All hardware identification data inscribed on the name plates and markings shall be taken from and agree with production drawings and/or their engineering release records.

## 4. QUALITY ASSURANCE PROVISIONS

4.1 General: The supplier shall be responsible for the performance of all inspection requirements as specified herein.

4.1.1 Inspection Lev 1: The wheel assembly shall be tested and inspected at the assembly level.

4.2 Acceptance Tests: The wheel assembly shall be tested at ambient temperatures and pressures attached to either a holding fixture simulating the traction drive interface or an actual traction drive assembly.

4.2.1 Wheel Deflection Measurement: The wheel assembly shall be mounted and locked in a fixture as specified in paragraph 4.2 and a vertical force of 57 lbs shall be applied to the tire mesh. The deflection shall be as specified in paragraph 3.1.1. The wheel shall be rotated 90° and the test shall be repeated 3 times until 4 positions on the wheel at right angles to each other have been tested and measured.

# SPECIFICATION

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CODE IDENT NO. 1160	

4.2.2 Dimensional Inspection: The overall wheel assembly dimensions shall be measured and verified with the requirements of paragraph 3.2.1.

4.2.3 Wheel Assembly Weight: The complete wheel assembly shall be weighed and verified with the requirements of paragraph 3.2.2.

4.2.4 Freewheeling Test: The unloaded wheel assembly, when unlocked in the freewheeling condition per paragraph 3.2.3 shall require a maximum torque of 15 lb-in to start rotating. The test fixture shall represent minimum clearance conditions.

4.2.5 Workmanship: Workmanship shall be inspected to verify that the requirements of paragraph 3.2.4 have been met.

4.2.6 Identification Inspection: The wheel assembly shall be inspected to verify that all identification and markings have been applied in accordance with paragraph 3.2.5.

## 5. PREPARATION FOR DELIVERY

5.1 Cleaning and Preservation: All deliverable assemblies shall be cleaned and preserved in accordance with AC-DRL standard practice.

5.2 Packaging: All deliverable assemblies shall be packaged for safe transportation by common carrier.

## 6. NOTES

None